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THE PROPERTIES OF SALT-FORM COMPOUNDS OF VARIABLE COMPOSITION AND VIEWS ON THEIR CHEMICAL STRUCTURE

S.M. Ariia and M.P. Morozova

In connection with the problem of whether a chemical compound has an inherently fixed or variable composition, for compounds in which appreciable deviations from a stoichiometric composition are possible, the range of these deviations is one of the most important problems of general chemistry.

The work of N.S. Kurnakov is of decisive significance in the development of this problem, having an enormous effect on contemporary ideas about chemical combination. The subsequent emergence and rapid development of the x-ray diffraction method of investigating solid bodies made possible an approach to an understanding of the views put forward by N.S. Kurnakov with regard to structural ideas.

The experience accumulated in the course of x-ray crystallographic investigations was generalized by the efforts of a whole series of chemical crystallographers. It was noted that compounds of variable composition (CVC's) consist of subtraction, interstitial or substituted lattices [1-8].

These aspects constitute the basis on which the investigation of CVC's is being developed (the thermodynamics of CVC's are studied quite inadequately). Such typical CVC's as ferrous oxide FeO_{1+x}, titanous oxide $TiO_{1\pm x}$ and vanadous oxide $VO_{1\pm x}$, are considered as defective structures of the NaCl type, namely subtractive lattices based on this structure. It is considered that in the general case both in the metal-atom and in the oxygen-atom sub-lattice there is a certain proportion of vacant positions (differing in the two sub-lattices). The electroneutrality of the lattices requires the presence in the metal-atom sub-lattice of atoms in a valence state differing from that of the majority. In these circumstances the distribution of both these atoms and the vacant positions in the lattice is uniform and generally statistically disordered.

The problem of the present paper is the examination of the form of the relationship between certain properties, in the first case the thermodynamic characteristics, and composition of some binary systems containing CVC's.

1. Enthalpy of Formation, Gram-Formula Volume, Entropy

In all cases so far examined, the enthalpy of formation of oxides of variable composition (FeO_{1+x} [9], TiO_{1+x} [10], VO_{1+x} [11]) is a linear function of composition. Moreover, the enthalpy of formation of the substances lies within the limits of the region of homogeneity and is practically equal to the enthalpy of formation of a mixture of the same empirical composition of certain compounds of the corresponding systems. Thus, the enthalpies of formation of substances of the composition $TiO_{1.00}-TiO_{1.20}$, $VO_{1.00}-VO_{1.27}$ or $FeO_{1.04}-FeO_{1.11}$ ($TiO_{1.20}$, $VO_{1.27}$, $FeO_{1.11}$ – the upper boundaries of the region of homogeneity) coincide very accurately with the enthalpies of formation of mixtures of the same empirical composition of the oxides $MeO_{1.00}$ and $MeO_{1.50}$.

The enthalpy of formation of substances lying within the composition interval $TiO_{1.00}$ and $TiO_{0.89}$ (the lower boundary of the region of homogeneity of titanous oxide) is close to the enthalpy of formation of a mixture of $TiO_{1.00}$ and $TiO_{0.48}$ (the upper boundary of the region of homogeneity of the compound lowest in oxygen in the system Ti-O).

The relationships recorded are given in Figs. 1-3.

The generally known fact that the enthalpy of polymorphic transformation of binary compounds is rather

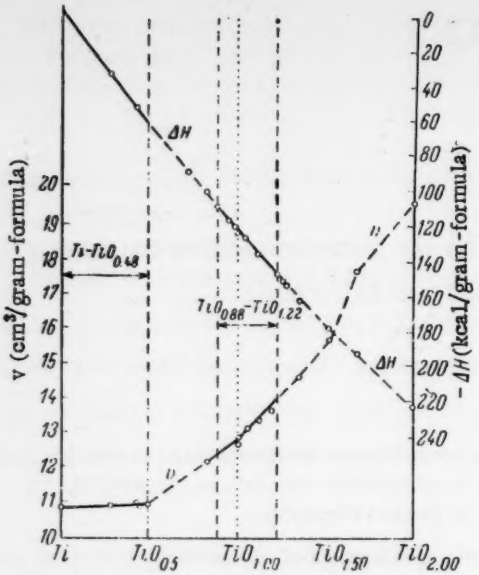

Fig. 1. Variation of enthalpy of formation (in kcal per gram-formula) and gram-formula volume (in cm^3) of titanium oxides with composition.

small in absolute magnitude, indicates that the relationship between enthalpy of formation (which is in principle a structure-dependent magnitude) and type of lattice is not very significant.

At the same time, the enthalpies of formation of those discrete compounds of the elements of the transition groups in which these elements act in two different valence states differ rather appreciably from the enthalpies of formation of a mixture, of the same empirical composition, of those compounds in each of which the element of the transition group acts only in one of the two valence states which coexist in the lattice of a mixed compound (thus the heat of formation of $MnO_{1.33}$ is 3.6 kcal greater than the heat of formation of a mixture of $MnO_{1.00}$ and $MnO_{1.50}$ of the same empirical composition [12] and the heat of formation of $WO_{2.67}$ is 2.5 kcal less than the heat of formation of a mixture of WO_2 and WO_3 of the same empirical composition). Thus, the relationship of the change of enthalpy of formation of some CVC's with composition is not a simple effect, as for example, in the FeO_{1+x} lattice where the iron occurs in the same valence states, being in the forms $FeO_{1.00}$ and $FeO_{1.50}$.

The equality of the enthalpy of formation of substances lying within the limits of the region of homogeneity and the enthalpy of formation of mixtures, of the same empirical composition, of certain specific compounds of the corresponding system is undoubtedly a consequence of the structural peculiarities of the lattices of such CVC's.

According to the classical structural model of CVC's, in the MeO_{1+x} lattice the atoms of Me^{III} and the vacant positions are distributed uniformly and in statistical disorder. In this case Madelung's constant would have been different from that for a mixture of the $MeO_{1.00}$ and $MeO_{1.50}$ lattices and, correspondingly, the electrostatic interaction energy in the MeO_{1+x} lattice must differ from the electrostatic interaction energy in a mixture of $MeO_{1.00}$ and $MeO_{1.50}$.

In the $MeO_{1.00}$ and $MeO_{1.50}$ lattices the Me^{II} and Me^{III} atoms occur in a state of specific exchange interaction (this is shown, in particular, by the magnetic properties of compounds of elements of the transition groups) which introduces a definite component into the energy of the lattice and consequently also to the enthalpy of formation.

In MeO_{1+x}, according to the classical structural model, the atoms of Me^{III}, while being uniformly distributed, are placed far apart (for example, in the composition $MeO_{1.05}$); consequently, the exchange interaction between them is hindered and must be superseded in the main by the interaction between Me^{III} and Me^{II} which is characterized by another energy effect.

It would seem that this fact also must require an enthalpy of formation differing from the enthalpy of formation of a mixture of $MeO_{1.00}$ and $MeO_{1.50}$ of the same empirical composition, for substances lying within the limits of the region of homogeneity.

Figure 2, which illustrates the variation of the enthalpy of formation in the system Fe–O, incidentally gives rise to the following consideration. The heat of formation of $FeO_{1.33}$ is appreciably greater than the heat of formation of a mixture of $FeO_{1.00}$ and $FeO_{1.50}$, evidently because of the uniform distribution of Fe^{II} and Fe^{III} atoms in the lattice which obviously occurs in a condition of special, specific interaction.

If such a uniform distribution of Fe^{II} and Fe^{III} had taken place in the FeO_{1+x} lattice, then probably the enthalpy of formation of the substance of composition FeO_{1+x} would have been near to that of a mixture of $FeO_{1.00}$ and $FeO_{1.33}$ and not of a mixture of $FeO_{1.00}$ and $FeO_{1.50}$, which, in fact, occurs. It seems to us that the zero enthalpy of mixing of $FeO_{1.00}$ and $FeO_{1.50}$ on formation of FeO_{1+x} can be considered as an indication that in this

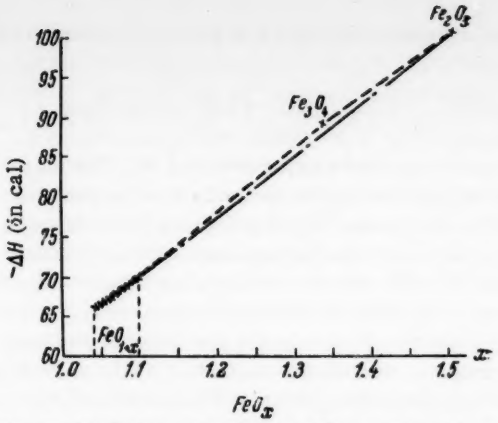

Fig. 2. Variation of enthalpy of formation of iron oxides (in kcal per gram-formula) with composition of the oxides.

case the classical model of a CVC lattice is not formed, but a submicro-inhomogeneous structure arises – the $FeO_{1.00}$ lattice in which islands of agglomerates of Fe^{III} are disseminated (in conjunction, of course, with atoms of oxygen in the appropriate ratio).

In the light of what has been said above it is obvious that the practical equality of the enthalpy of formation of substances lying within the region of homogeneity to that of mixtures of the corresponding compounds of the same empirical composition must be in accordance with such a submicro-inhomogeneous structure. It is evident that the proximity of the gram-formula volumes of substances lying within the region of homogeneity to that of mixtures of the corresponding compounds must also be in accordance with the submicro-inhomogeneous structure of lattices of CVC's.

As is seen from Fig. 1, this actually occurs in the system Ti–O [13]. The gram-formula volume of VO_{1+x} is a little smaller than that of a mixture of $VO_{1.00}$ and $VO_{1.50}$ of the same empirical composition.

The reason, at least in part, is that it cannot, of course, be assumed in principle that all the Me^{III} atoms in the Me_{1+x} lattice, without exception, enter into the composition of their agglomerates. A certain proportion of the Me^{III} atoms (we will discuss this in detail below) must occur "one by one" within the limits of the basic lattice, which cannot but give rise to the known deviation of certain properties from additivity.

The entropy of ferrous oxide, FeO_{1+x} as a function of composition is shown in Fig. 4. It is clearly evident that it is greater than the entropy of a mixture of $FeO_{1.00}$ and $FeO_{1.50}$ of the same empirical composition. This fact is also responsible for the possibility of a thermodynamically stable state of homogeneous (in the ordinary sense) substances of the composition FeO_{1+x} in comparison with a mixture of $FeO_{1.00}$ and $FeO_{1.50}$ and even in comparison with a mixture of $FeO_{1.00}$ and $FeO_{1.33}$ (Fe_3O_4).

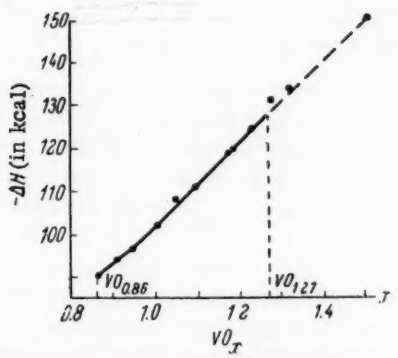

Fig. 3. Variation of enthalpy of formation of vanadium oxides (in kcal per gram-formula) with composition of the oxides.

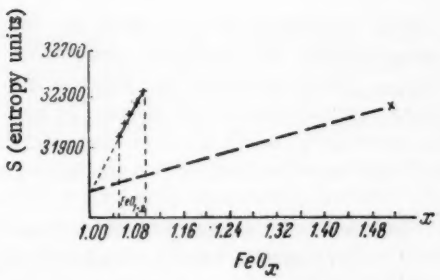

Fig. 4. Variation of entropy of iron oxides (in entropy units) with composition of the oxides at 1104°K.

It should be noted that the submicro-inhomogeneous lattice that we postulate for certain CVC's must behave thermodynamically as a single phase since the agglomerates of Me^{III} atoms cannot be regarded as independent formations. Because of the low values of their numbers, interactions of their component Me^{III} atoms and the atoms of the nonmetallic element with the particles of the basic lattice are of great significance. The submicro-inhomogeneous structure in question is by no means equivalent to a mechanical mixture of the corresponding compounds.

2. The Magnetic Susceptibility and Electrical Conductivity of Iron Oxides at High Temperatures

As has been shown previously [14] the magnetic susceptibility of ferrous oxide at high temperatures is a linear function of composition. Furthermore, the magnetic susceptibility is practically the same as that of a mixture of low-oxygen ferrous oxide and ferric oxide, of the same empirical composition (Fig. 5). The magnetic susceptibility of $FeO_{1.50}$ (Fe_2O_3) is considerably lower than that which should occur in the absence of antiferromagnetic interaction between the Fe^{III} atoms. At the same time it is known that in going over from the Fe_2O_3 to the $Fe_2(SO_4)_3$ lattice the magnetic susceptibility, calculated on 1 gram-atom of Fe^{III}, rises to a value in conformity with the ionic model since a separation of the Fe^{III} atoms from one another takes place and this eliminates the possibility of antiferromagnetic interaction. According to Selwood [15] the same thing occurs on diluting ferric oxide with aluminum oxide. If the FeO_{1+x} lattice were characterized by the uniform distribution of Fe^{III} atoms in it, it would seem that the antiferromagnetic interaction between the Fe^{III} atoms even in this case, should be weakened to a considerable extent, because even at a composition of $FeO_{1.10}$ there are four atoms of Fe^{II} to one atom of Fe^{III}, i.e., the Fe^{III} atoms should be sufficiently separated from one another.

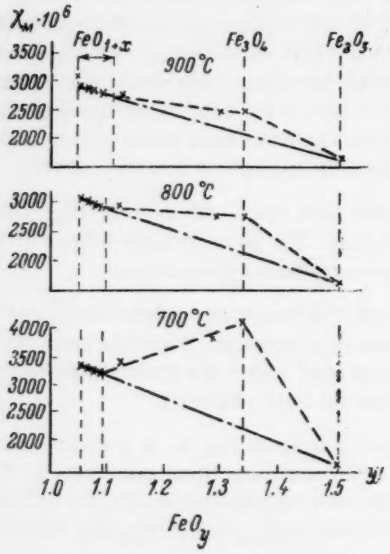

Fig. 5. Variation of magnetic susceptibility of iron oxides with composition at high temperatures.

In the light of this it can be surmised that the equality of the magnetic susceptibility of FeO_{1+X} to that of a mixture of $FeO_{1.00}$ and $FeO_{1.50}$ of the same empirical composition indicates that segregation of the Fe^{III} atoms, and not a uniform distribution of these in the lattice, takes place. It should also be noted that the $FeO_{1.33}$ lattice, in which the Fe^{III} and Fe^{II} atoms are distributed uniformly, is characterized, as is known, by ferromagnetic properties. It can be surmised that if such a distribution, postulated by the classical model of CVC lattices, should occur in FeO_{1+X} the latter should have had, if only in embryo, elements of this ferromagnetic interaction. The magnetic susceptibility of FeO_{1+X} should approximate that of a mixture of $FeO_{1.00}$ and $FeO_{1.33}$, which is not, in fact, observed.

Aubry and Marion [16] measured the electrical conductivity of ferrous oxides of various compositions at high temperatures. The electrical conductivity of FeO_{1+X} differs qualitatively from that of a mixture of $FeO_{1.00}$ and $FeO_{1.50}$. We stated above that together with agglomerates of Fe^{III} atoms an isolated distribution of these (and vacant positions) must also occur. On such properties as enthalpy of formation and magnetic susceptibility this has practically no effect, but on electrical conductivity – a property that is very strongly dependent on "impurities" and defective lattices – it can have a very marked effect.

3. Statistical-Thermodynamic Examination of the Problem of the Chemical Structure of Compounds of Variable Composition

Let us suppose that in the system A–B there are stoichiometric compounds $AB_{1.00}$ and $AB_{1.50}$ and let us suppose that there is a region of homogeneity from the composition $AB_{1.00}$ to AB_{1+X} ($1 + x < 1.5$, B is a divalent element). If the CVC $AB_{1.00}$–AB_{1+X} has the structure specified by the classical model, and at the same time substances of a composition included in this interval are formed from $AB_{1.00}$ and $AB_{1.50}$ without change in enthalpy, as occurs in a number of cases mentioned above, then their thermodynamic stability is determined by their greater entropy value with respect to a mixture of $AB_{1.00}$ and $AB_{1.50}$. This increased entropy is explained by an increased number of micro states brought about by different possibilities of substitutions of the vacant positions in the lattice.

If AB_{1+X} is formed endothermically from $AB_{1.00}$ and $AB_{1.50}$, then the classical model of the structure of the AB_{1+X} lattice must correspond to a higher entropy value because the vibrational frequencies of the atoms change correspondingly. However, if the endothermal effect is sufficiently great in its absolute magnitude the classical

model lattice formation will be thermodynamically unfavorable because the increase in entropy will not be compensated by an increase in enthalpy. This case occurs, in particular, when the specific exchange interaction of A^{II} with A^{II} and A^{III} with A^{III} atoms results in a more significant lowering of the energy of the system than does the exchange interaction of A^{II} with A^{III}.

In this case a lattice of submicro-inhomogeneous structure can arise which, as stated above, under certain conditions can be formed from $AB_{1.00}$ and $AB_{1.50}$ with a practically zero heat effect.* At the same time, because the postulated agglomerates of A^{III} atoms cannot necessarily be considered as stable formations, but rather as continuously forming and disrupting formations of submicro-inhomogeneous structure, there must also be a concomitant increase in entropy. As a rule, the structure $AB_{1.50}$ can be obtained from the structure $AB_{1.00}$ by removing from the latter a definite proportion of A atoms (if close packing of B atoms forms the basis of both structures) with corresponding, simultaneous changes in the grouping of the component particles. In the light of this, in the A^{III} agglomerate region, in comparison with the $AB_{1.00}$ structure, there are vacant positions which, as a result of the dynamic nature of the A^{III} atom agglomerates, can also be distributed variably in the lattice: a vacant position can occur at any point in the A-atom sub-lattice. Correspondingly, also in the case of formation of a submicro-inhomogeneous lattice from $AB_{1.00}$ and $AB_{1.50}$, an increase in entropy must occur.**

A conclusion on the possibility of the agglomeration of A^{III} atoms in the AB_{1+X} lattice in the case when the latter is formed from $AB_{1.00}$ and $AB_{1.50}$ without change in enthalpy, can be arrived at by examining this question from the point of view of the fluctuation theory.

Let us assume (though this is very improbable, as we have stated above) that the AB_{1+X} lattice with a uniform distribution of A^{III} atoms and vacant positions is formed from $AB_{1.00}$ and $AB_{1.50}$ without change in enthalpy. Obviously, in this case a lattice of submicro-inhomogeneous structure should be formed (more probably) without change in enthalpy. In accordance with this the occurrence of agglomerates of A^{III} atoms in the AB_{1+X} lattice, in the form of fluctuations must be accompanied by a practically zero change in enthalpy and a certain decrease in entropy, i.e., it must be accompanied by an insignificant increase in thermodynamic potential and this is just the right condition for a high probability for such fluctuations to occur.

It is appropriate to note in this connection that the assumption of the necessity of fluctuations of concentration in liquid solutions was used very fruitfully by M.I. Shakhparonov [17, 18].

The submicro-inhomogeneous structure of CVC lattices and the uniform distribution therein of atoms not in the principal valence state of the majority, and of vacant positions, should be regarded as two extreme types of chemical structure of such compounds. In an actual CVC lattice, submicro-inhomogeneous elements, segregation of A^{III} atoms and isolated distribution of these in the lattice must all occur.

The extent to which the structure of a given CVC approximates one of these extreme types must depend, above all, on the nature of the compound and also on temperature and the magnitude of the deviation of the compound from a stoichiometric composition. An increase in the extent of the deviation from a stoichiometric composition should draw the lattice structure toward the extreme case of a submicro-inhomogeneous structure; an increase in temperature should act in the opposite direction.

In the systems metal–carbon [19], metal–sulphur, metal–metal [20] other relationships between change in enthalpy of formation and other properties of the CVC's with composition are observed; it can be surmised accordingly that submicro-inhomogeneous elements enter into their lattices to a lesser extent. It is without doubt, however, that there must be submicro-inhomogeneous elements, particularly near the upper boundary of the region of homogeneity.

What is the structure in the region of agglomerates of A^{III} atoms in the AB_{1+X} lattice? Is it the same as that of the compound $AB_{1.50}$, or, in spite of the segregation of A^{III} atoms everywhere, is the same $AB_{1.00}$ structure maintained in all lattices?

*It is quite clear that not all compounds of $AB_{1.00}$ and $AB_{1.50}$ can form such submicro-inhomogeneous lattices isoenthalpically. This is possible only for a certain relationship of the structures of $AB_{1.00}$ and $AB_{1.50}$, the characteristics of which are as yet unknown.

**It will be lower than in the case of uniform, statistically disordered distribution of vacant positions because in the case of the segregation of A^{III} the distribution of individual vacant positions does not take place independently of one another.

It will not be possible to draw any reliable conclusions in this direction until experimental data are available. Furthermore, it is clear that the outline of the chemical structure of CVC's postulated still needs careful verification by a whole series of experimental methods.

SUMMARY

Examination of the nature of the variation of certain properties with composition in binary systems of compounds of variable composition and also a statistical-thermodynamic examination of the question of the chemical structure of compounds of variable composition, lead to the conclusion that in the lattices of the latter, segregation of atoms of the transition groups, that are in different valence states, occurs to some degree or other.

In other words, the lattices of compounds of variable composition, in a number of cases can have a submicro-inhomogeneous structure (while remaining as a single phase in the thermodynamic sense).

The proportion of elements of submicro-inhomogeneous structure must depend on the nature of the compound, on temperature and on the degree of deviation of the CVC from a stoichiometric composition.

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STUDY OF DOUBLE SULFATES OF AMERICIUM BY ABSORPTION SPECTRA IN CRYSTALS

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In this work the ordinary sulfate of americium and its double sulfates with potassium, thallium, rubidium and cesium were studied. The ordinary sulfate and the following double sulfates of americium were identified as:

$Am_2(SO_4)_3 \cdot 5H_2O$

$KAm(SO_4)_2 \cdot 2H_2O$
$TlAm(SO_4)_2 \cdot 4H_2O$
$RbAm(SO_4)_2 \cdot 4H_2O$
$CsAm(SO_4)_2 \cdot 4H_2O$

$K_3Am(SO_4)_3 \cdot H_2O$

$K_8Am_2(SO_4)_7$
$Tl_8Am_2(SO_4)_7$
$Cs_8Am_2(SO_4)_7$

The absorption spectra of polycrystalline samples of the compounds were investigated in the region 4000 to 8500 A at 300, 200 and 80°K. The peak separation of the electronic bands of Am^{+++} in the 5000 A region was examined and the electronic-vibrational "lines" for the compounds in question in the 4500 A region were identified. The effect of water of crystallization on the nature of the peak separation of the 5000 A electronic bands and on the nature of the electronic-vibrational "lines" in the 4500 A region was examined.

It is known that the double sulfates of rare earth elements and alkali metals have poor solubility and as a consequence of this they play an important role in the analytical chemistry of these elements. In conformity with the actinide theory, the transuranium elements are analogous to the rare earth elements and a number of their compounds have similar chemical properties, in particular, the similarity of the double sulfates with alkali metals.

There are data in the literature about identified double sulfates of neodymium with potassium, sodium and ammonium [1] and double sulfates of cerium and samarium with sodium [2].

Of the double sulfates of the transuranium elements with alkali metals, the system $R_2SO_4 - Pu_2(SO_4)_3 - H_2O$ (where R = K, Tl, Rb or Cs) has been studied most fully [1]. From the example of the systems of the double sulfates of Pu and Nd, the similarity of this class of actinide compound with the corresponding lanthanide compounds was demonstrated; in particular, the isomorphism of $NaPu(SO_4)_2 \cdot H_2O$, $KPu(SO_4)_2 \cdot 2H_2O$, $NH_4Pu(SO_4)_2 \cdot 4H_2O$ with the analogous neodymium compounds was shown by the results of x-ray structural analysis [1].

Similarity of the spectra of hydrated ions of the actinides and lanthanides was shown by investigations on the spectrophotometry of solutions of the actinide compounds, these spectra being characterized by narrow, sharp absorption bands in the ultraviolet, visible and near-infrared regions. This similarity, which is connected with the presence in the elements of both families of completed f-electron shells, enables an analysis of the relationships characteristic of the spectra of f-elements in crystals to be made on the example of the lanthanides, the literature on which is quite voluminous.

The appearance of structure in the absorption bands of lanthanides in crystals (noted by many authors [3-8]) indicates that in the crystal an absorbing ion falls within the sphere of action of fields created by the association of charges entering into the crystal lattice. This brings about a splitting of energy levels of the ion into a number of components and a group of "lines" appears which corresponds to exchange between the components of the separated energy levels. On the basis of the observed structure of the absorption bands brought about by electronic transitions, an idea can be obtained about the electrical fields in the crystal lattice which enable the f-element ions to be used as optical probes in crystals.

In the spectrum of neodymium salts, Ewald [3] discovered a group of weak, sharp "lines" with spacings of some hundreds of cm^{-1} on the shortwave side of each electronic band.

Accurate measurements of the frequency difference showed their coincidence with the natural vibrational frequencies of ions and polar molecules, known from the data of Raman and vibrational infrared spectra. These "lines" were identified as electronic-vibrational lines arising from the superposition of lattice vibrations on the electronic transitions. These "lines" were shown to be very sensitive to isomorphic change of the lattice components.

This effect should appear to a very marked extent in the case of $5f$-elements because the $5f$-shell is energetically and spatially more subject to external electrical action than the $4f$-shell of lanthanides. This property makes actinide ions still more suitable for the study of the internal nature of crystals.

Data on the absorption spectra of actinide compounds in crystals are few and are of a qualitative nature. The absorption spectra of UCl_3, $NpCl_3$, $PuCl_3$ and $AmCl_3$ have been investigated in comparison with the spectrum of $NdCl_3$ for the purpose of drawing an analogy with the lanthanides [9]. The absorption spectra of crystals of UF_4 and of the double fluorides of U(IV) with sodium and potassium have been described [10], and on the basis of the similarity of the absorption spectra it was concluded that these compounds are isomorphic. The absorption spectrum of $AmCl_3 \cdot H_2O$ has also been studied [11].

EXPERIMENTAL

Preparation and Analysis of the Ordinary and Double Sulfates of Americium With Potassium, Thallium, Rubidium and Cesium

The isotope Am^{241} was used for the preparation of all the compounds. The ordinary sulfate of americium was prepared by dissolving the dioxide AmO_2, obtained by calcination of the hydroxide $Am(OH)_3$ at 750-850°, in 8 M H_2SO_4. The solution was diluted to an acidity of 0.5 M H_2SO_4 and ethanol was added until a precipitate separated. The precipitate was removed, washed three times with ethanol and dried in vacuo to constant weight at 20°.

For the preparation of the double sulfates of americium with potassium, thallium, rubidium and cesium, different volumes of standard solutions of the ordinary sulfates of the metals were added to the solution of $Am_2(SO_4)_3$ at an acidity of 0.5 M H_2SO_4, such as to give the different ratios of $M_R{}^+/M_{Am}{}^{+++}$. For low molar ratios of $M_R{}^+/M_{Am}{}^{+++}$, in order to accelerate the precipitation of the correspondingly little-soluble double sulfates, ethanol was added in the ratio 1/20, by volume. The precipitates obtained were separated, washed four times with 50% ethanol in 0.1 M H_2SO_4, twice in 50% methanol in 0.1 M H_2SO_4 and dried in vacuo to constant weight at 20°.

The air-dried precipitates were analyzed for their contents of americium, SO_4^{--} and water. Americium was determined radiometrically in a slit ionization chamber filled with argon, and by a gravimetric method as AmO_2. The SO_4^{--} ion was determined gravimetrically as $BaSO_4$. Water was determined by the difference between the weight of the air-dried precipitate and that of the precipitate after calcining at 350-400°. In the case of the double potassium-americium sulfates, a colorimetric analysis for potassium as the dipicrylaminate [12] was also carried out.

The ordinary sulfate and the double potassium-americium sulfates. From the analytical data the formula $Am_2(SO_4)_3 \cdot 5H_2O$ was assigned to the ordinary americium sulfate prepared by the method described above.

A phase diagram was plotted for the system $K_2SO_4-Am_2(SO_4)_3-H_2O$ in the region of $M_K{}^+/M_{Am}{}^{+++}$ from 3.0 to 418.0 and the following compounds were identified:

$KAm(SO_4)_2 \cdot 2H_2O$	$M_{K^+}/M_{Am^{+++}}$ from 3.7 to 10.0
$K_3Am(SO_4)_3 \cdot H_2O$	$M_{K^+}/M_{Am^{+++}}$ from 10.3 to 37.9
$K_8Am_2(SO_4)_7$	$M_{K^+}/M_{Am^{+++}}$ from 43.0 to 418.0

The phase diagram of the system $K_2SO_4-Am_2(SO_4)_3-H_2O$ is given in Fig. 1. Analytical data for the ordinary sulfate and for the double sulfates of americium with potassium are set out in Table 1. In Table 2 data are given on the determination of the solubility of the double potassium-americium sulfates.

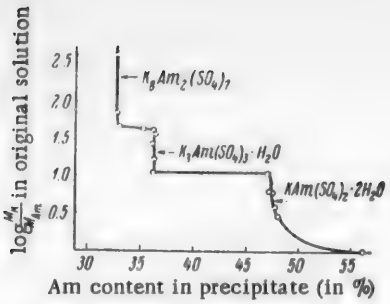

Fig. 1. Phase diagram of the system $K_2SO_4-Am_2(SO_4)_3-H_2O$.

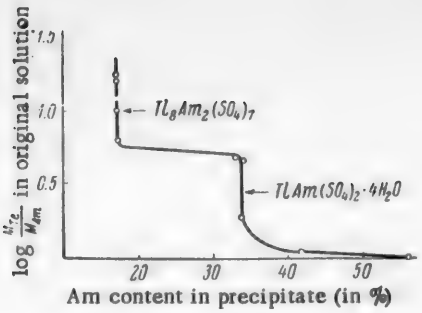

Fig. 2. Phase diagram of the system $Tl_2SO_4-Am_2(SO_4)_3-H_2O$.

TABLE 1

Analysis of the Single Sulfate and Double Potassium-Americium Sulfates

Compound	K content (%)		Am content (%)		SO_4^{--} content (%)		H_2O content (%)	
	found	calc.	found	calc.	found	calc.	found	calc.
$Am_2(SO_4)_3 \cdot 5H_2O$	—	—	56.1±0.2	56.0	33.5 ± 0.3	33.5	10.4±0.2	10.4
$KAm(SO_4)_2 \cdot 2H_2O$	—	7.7	47.4±0.3	47.4	—	37.8	7.2±0.2	7.1
$K_3Am(SO_4)_3 \cdot H_2O$	18.3	17.6	36.3±0.2	36.3	41.7	43.3	2.5	2.7
$K_8Am_2(SO_4)_7$	20.9	21.3	32.8±0.2	32.8	46.0	45.8	—	—

TABLE 2

Solubility of the Double Potassium-Americium Sulfates at 20°

$M_{K^+}/M_{Am^{+++}}$	Volume of ethanol added (in ml)	Solubility (g Am/liter)	Content of americium in precipitate (in %)	Composition of precipitate
418.0	0.20	0.003	32.8	$K_8Am_2(SO_4)_7$
73.5	—	0.014	32.8	$K_8Am_2(SO_4)_7$
48.5	—	0.030	33.0	—
45.5	—	0.020	35.3	—
43.2	—	0.020	36.2	—
37.9	—	0.040	36.4	$K_3Am(SO_4)_3 \cdot H_2O$
27.3	—	0.050	36.1	$K_3Am(SO_4)_3 \cdot H_2O$
17.0	—	0.120	36.2	$K_3Am(SO_4)_3 \cdot H_2O$
10.0	0.03	0.160	36.3	—
6.4	0.03	2.800	47.2	$KAm(SO_4)_2 \cdot 2H_2O$
6.3	—	—	47.5	$KAm(SO_4)_2 \cdot 2H_2O$
3.7	0.02	3.800	47.7	$KAm(SO_4)_2 \cdot 2H_2O$
3.0	0.02	—	48.0	$KAm(SO_4)_2 \cdot 2H_2O$

Double thallium-americium sulfates. A phase diagram was plotted for the system $Tl_2SO_4-Am_2(SO_4)_3-H_2O$ in the region of $M_{Tl^+}/M_{Am^{+++}}$ from 1.1 to 17.3 and the individual compounds $TlAm(SO_4)_2 \cdot 4H_2O$ and $Tl_8Am_2(SO_4)_7$ were identified.

These compounds were prepared by a method similar to that described above for the double potassium-americium sulfates.

The phase diagram of the system $Tl_2SO_4-Am_2(SO_4)_3-H_2O$ is shown in Fig. 2.

TABLE 3

Solubility of the Double Thallium-Americium Sulfates at 20°

$M_{Tl^+}/M_{Am^{+++}}$	Volume of ethanol added (in ml)	Solubility (g Am/liter)	Content of americium in precipitate (in %)	Composition of precipitate
17.3	—	1.40	17.3	$Tl_8Am_2(SO_4)_7$
15.8	0.08	1.30	17.3	$Tl_8Am_2(SO_4)_7$
10.9	0.10	2.20	17.3	$Tl_8Am_2(SO_4)_7$
6.3	0.06	4.20	17.4	$Tl_8Am_2(SO_4)_7$
4.8	0.06	—	33.2	—
4.5	0.04	4.60	34.2	$TlAm(SO_4)_2 \cdot 4H_2O$
1.9	0.03	5.70	33.9	$TlAm(SO_4)_2 \cdot 4H_2O$
1.1	0.03	6.00	40.8	—

TABLE 4

Comparison of the Ordinary Sulfate and Double Sulfates of Plutonium With the Corresponding Americium Compounds

Plutonium compounds	Americium compounds
$Pu_2(SO_4)_3 \cdot 5H_2O$	$Am_2(SO_4)_3 \cdot 5H_2O$
$Pu_2(SO_4)_3 \cdot 7H_2O$	He found
$KPu(SO_4)_2 \cdot 2H_2O$	$KAm(SO_4)_2 \cdot 2H_2O$
$KPu(SO_4)_2 \cdot H_2O$	He found
He found	$K_3Am(SO_4)_3 \cdot H_2O$
$K_8Pu_2(SO_4)_7$	$K_8Am_2(SO_4)_7$
$TlPu(SO_4)_2 \cdot 4H_2O$	$TlAm(SO_4)_2 \cdot 4H_2O$
$RbPu(SO_4)_2 \cdot 4H_2O$	$RbAm(SO_4)_2 \cdot 4H_2O$
$CsPu(SO_4)_2 \cdot 4H_2O$	$CsAm(SO_4)_2 \cdot 4H_2O$

In Table 3 results of the determination of the solubility of the double thallium-americium sulfates are given.

Double sulfates of americium with rubidium and cesium. A phase diagram was plotted for the system $Rb_2SO_4-Am_2(SO_4)_3-H_2O$ in the region of $M_{Rb^+}/M_{Am^{+++}}$ from 0.6 to 325.3 and a double sulfate of the composition $RbAm(SO_4)_2 \cdot 4H_2O$ was identified. No phase diagram was plotted for the system $Cs_2SO_4-Am_2(SO_4)_3-H_2O$. Two double sulfates were obtained that precipitated at the $M_{Cs^+}/M_{Am^{+++}}$ ratios of 51.7 and 129.1. For the compound obtained at the ratio $M_{Cs^+}/M_{Am^{+++}}$ of 51.7 the composition $CsAm(SO_4)_2 \cdot 4H_2O$ was found. The compound obtained at the ratio $M_{Cs^+}/M_{Am^{+++}}$ of 129.1 was not analyzed. The absorption spectrum of this double sulfate was recorded and the composition $Cs_8Am_2(SO_4)_7$ was assigned to this compound on the basis of the spectrographic data.

The following conclusions can be drawn from the analytical data and from the solubilities of the americium double sulfates identified.

1. The americium double sulfates have low solubility.

2. In the series of double sulfates of americium with potassium and thallium, the solubility decreases with increasing content of the monovalent cation: for the double sulfates with potassium from 3.80 to 0.003 g Am/liter, for the double sulfates with thallium from 6.00 to 1.40 g Am/liter.

3. The double thallium-americium sulfates have greater solubility than the corresponding double potassium-americium sulfates.

4. A double sulfate of the composition $R_3Am(SO_4)_3 \cdot H_2O$ was identified only in the case of potassium.

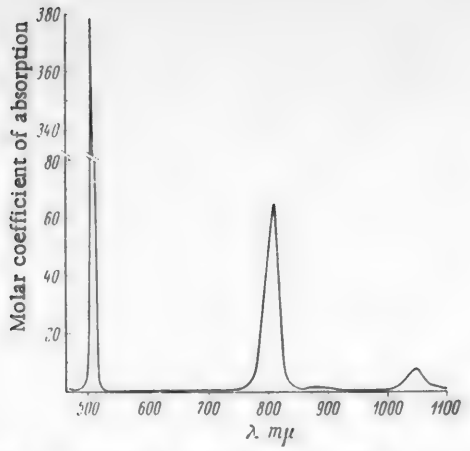

Fig. 3. Absorption spectrum of Am^{+++} in 0.2 M $HClO_4$.

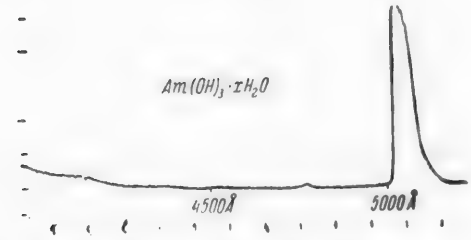

Fig. 4. Absorption spectrum of $Am(OH)_3$ in the region 4000-5200 A at 80°K.

5. The double thallium-americium sulfates are formed at lower molar ratios of M_R^+/M_{Am}^{+++} than the analogous double potassium-americium sulfates.

In Table 4 the known ordinary sulfates and double sulfates of plutonium are compared with the corresponding americium compounds studied by us.

Absorption Spectra of the Ordinary Sulfate and Double Sulfate of Americium With Potassium, Thallium and Cesium

The hydrated Am^{+++} ion is characterized by the occurrence of a small number of sharp, intense absorption bands widely separated from one another (5030, 8110 and 10500 A). The absorption spectrum of Am^{+++} in 2 M $HClO_4$ [13] is shown in Fig. 3. The comparative simplicity of the absorption spectrum of hydrated Am^{+++} makes this ion particularly suitable for the study of the absorption spectra of Am^{+++} compounds in crystals because it would be expected that electronic absorption bands in crystals will undergo specific peak separation and electronic-vibrational absorption bands will be uncovered which would be extremely difficult to interpret in the case of hydrated-ion absorption spectra of a complex nature.

In the present work the absorption spectra of the following compounds were plotted:

$Am_2(SO_4)_3 \cdot 5H_2O$	$KAm(SO_4)_2 \cdot 2H_2O$	$K_3Am(SO_4)_3 \cdot H_2O$	$K_8Am_2(SO_4)_7$
$Am_2(SO_4)_3$	$KAm(SO_4)_2$		$Tl_8Am_2(SO_4)_7$
	$TlAm(SO_4)_2 \cdot 4H_2O$		$Cs_8Am_2(SO_4)_7$
	$CsAm(SO_4)_2 \cdot 4H_2O$		

The anhydrous compounds $Am_2(SO_4)_3$ and $KAm(SO_4)_2$ were prepared by calcining the corresponding hydrated crystals at 350-400°. The method of preparing the samples for plotting absorption spectra was determined mainly by the necessity for deep cooling of the specimens during the plotting and for maintaining an approximately constant film thickness. The following method was worked out for the preparation of the specimens: between two flat, glass plates of 32 mm diameter, and 1 mm thickness is placed a "cambric cloth" washer of the same diameter and 0.12 mm thick with a central aperture of 5 mm diameter. In the space between the glass plates formed by this aperture, 4-5 mg of the crystals of the compound being investigated are placed and the glass plates are held together by a thin rubber ring. The whole system, together with a diaphragm of nonactinic paper of 5 mm diameter, was fixed in a special clamp and for low-temperature plots was lowered on an overhead support into a transparent Dewar vessel containing a cooling mixture. Two types of samples were used for examination – undiluted and diluted with fused potassium sulfate. Weak "lines" were plotted with undiluted samples, the specimens diluted with potassium sulfate were used for plotting the intense absorption bands.

Preliminary plots showed that dilution of the specimens with potassium sulfate does not alter the character of the spectrum but it lowers the absorption in the region of the intense bands sufficiently to enable the fine structure to be seen.

The absorption spectra were plotted on an ISP-51 three-prism, glass spectrograph with a camera of F = 270 mm, in the wavelength region from 4000 to 8500 A. The degrees of dispersion of the apparatus for the respective wavelengths were:

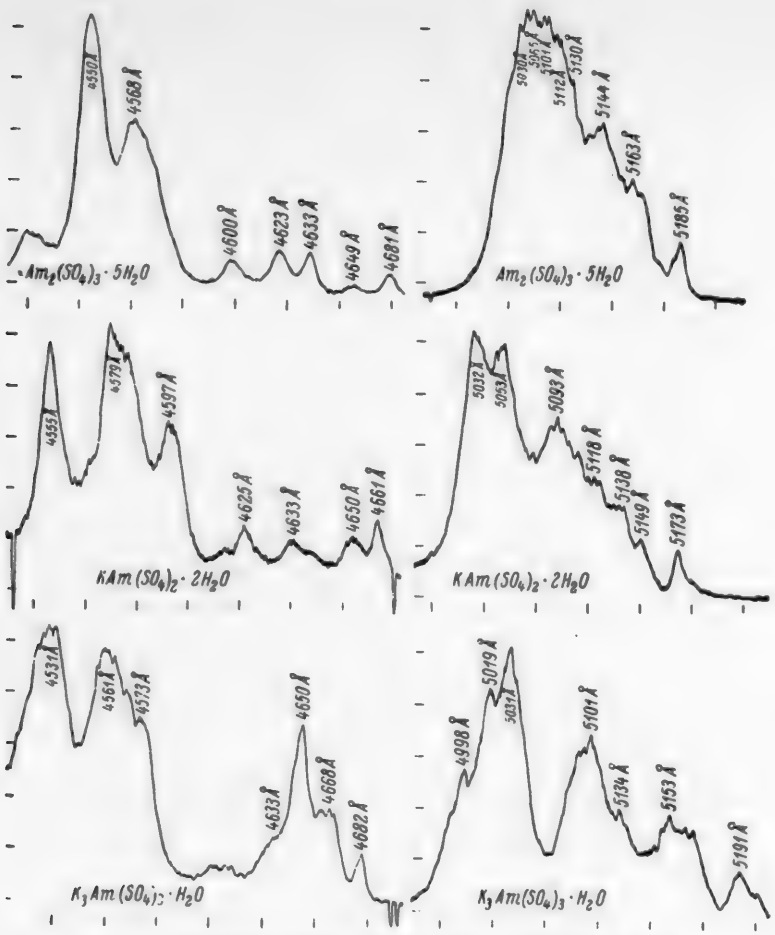

Fig. 5. Absorption spectra of americium compounds at 80°K.

A	A/mm
8000	196
7000	149
6000	87
5000	47
4500	28
4000	19

For plots in the 7000-8500 A region home-produced plates, "Infra-220 and 840," were used and also imported plates "Infrared 850, 950 and 1050." For plots in the 4000-5200 A region, Russian-produced isoorthochromatic contrast plates with a sensitivity of 45 GOST units were used. A 500-w incandescent lamp was used as the continuous spectrum source. Under these conditions the exposure times were from 10 seconds to 2 hours. The absorption spectra were recorded with a slit width of 0.025 mm. The spectra obtained were interpreted with the help of a reference spectrum (iron-arc spectrum) on an MIR-12 measuring microscope and were measured photometrically under standard conditions with an MF-4 recording microphotometer. Plotting of the absorption spectra was carried out at 300, 200 and 80°K (room temperature, the temperature of a mixture of excess solid carbon dioxide in acetone and the boiling point of nitrogen at atmospheric pressure). A $CuSO_4$ solution was used as heat-filter for plots at 300°K.

RESULTS OF MEASUREMENTS

From the absorption-spectrum plots of the materials studied in the region 4000-8500 A, it was discovered that the electronic bands of the hydrated Am^{+++} ion undergo specific peak separation in the 5030 and 8110 regions and in addition a group of "lines" was discovered that are not observed in Am^{+++} solutions or in the spectra of solid preparations of $Am(OH)_3$ (Fig. 4). Absorption bands were not found in the 5200-8000 A region. In the present work, attention was mainly concentrated on the peak separation in the intense electronic band at 5030 A and on the group of "lines" in the 4500 A region.

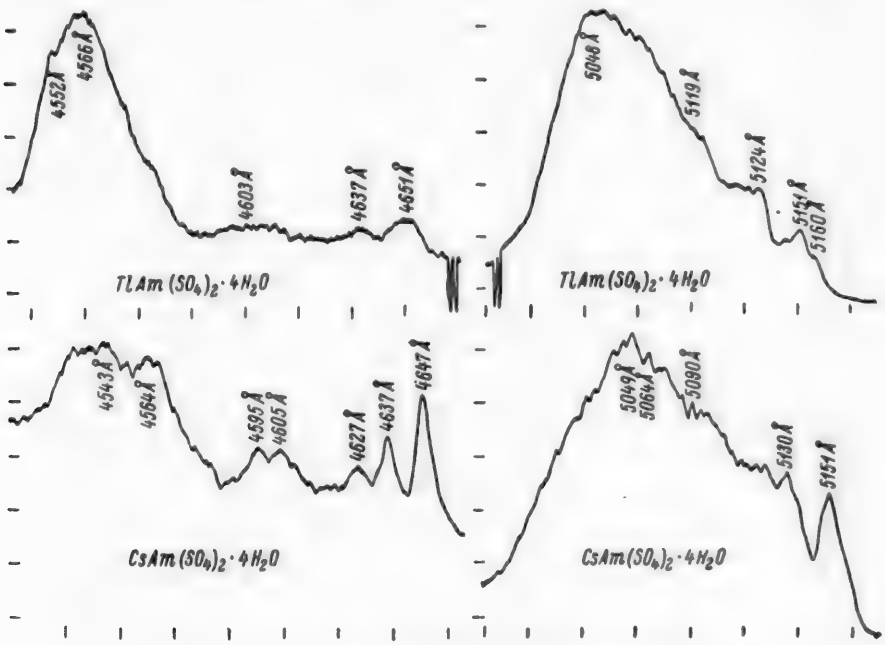

Fig. 6. Absorption spectra of americium compounds at 80°K.

Photomicrograms of the absorption spectra of the compounds indicated in the region 4500-5200 A at 80°K are shown in Figs. 5-8. Figure 9 shows photomicrograms of the absorption spectra of the double sulfate of americium and cesium precipitated at a ratio of $M_{Cs^+}/M_{Am^{+++}}$ of 129.1, at 300, 200 and 80°K.

As a secondary result a change in the absorption spectrum of the ordinary sulfate $Am_2(SO_4)_3 \cdot 5H_2O$ with time was noted, which is probably caused by disruption of the crystal lattice by α-irradiation from Am^{241}. Figure 10 shows an absorption-spectrum photomicrogram of the ordinary americium sulfate $Am_2(SO_4)_3 \cdot 5H_2O$ in the 4500 A region, recorded 15 days after preparation.

Figure 11 shows the peak separation in the split electronic band at 8110 A for $K_3Am_2(SO_4)_7$ at 80°K.

The wavelengths and wave numbers of the absorption-band maxima are shown in Table 5 for all the compounds examined, at 80°K in the 4500-5200 A region.

In Table 6 the magnitudes of the splitting of the 5030 A electronic bands at 80°K are quoted for the compounds studied.

DISCUSSION OF RESULTS

The data of Table 6 show that the absolute magnitude of the peak separation of the 5030 A electronic band of Am^{+++} is on the average considerably greater than that, for example, of neodymium or europium.

The increase in statistical interaction involved in the greater peak separation in the case of the actinides is possibly connected with an increase of the effective nuclear charge since the ionic radii of lanthanides and

TABLE 5

Wavelengths and Wave Numbers of the Absorption-Band Maxima for the Americium Compounds Studied, in the 4500-5200 A Region at 80°K

λ (Å)	ν (cm^{-1})
$Am_2(SO_4)_3 \cdot 5H_2O$	
4550	21978
4568	21891
4600	21751
4623	21631
4633	21584
4649	21510
4681	21363
5030	19880
5060	19741
5101	19602
5112	19562
5130	19491
5144	19440
5163	19369
5185	19286
$KAm(SO_4)_2 \cdot 2H_2O$	
4555	21954
4579	21836
4597	21753
4625	21621
4633	21584
4650	21505
4661	21455
5032	19873
5053	19720
5093	19634
5118	19536
5138	19463
5149	19419
5173	19331
$K_3Am(SO_4)_3 \cdot H_2O$	
4531	22070
4561	21925
4573	21867
4633	21584
4650	21505
4668	21422
4682	21358
4998	20008
5019	19924
5031	19879
5101	19602
5134	19478
5153	19406
5191	19264
$K_8Am_2(SO_4)_7$	
4556	21929
4568	21891
4649	21510
4665	21436
4995	20018
5033	19867
5066	19749
5081	19679
5101	19602
5126	19508
5149	19419
5171	19337
5181	19299
$Tl_8Am_2(SO_4)_7$	
4558	21937
4574	21863
4592	21774
4634	21577
4656	21477
5004	19984
5028	19888
5076	19700
5104	19592
5131	19489
5151	19414
5177	19316
5190	19269
$Cs_8Am_2(SO_4)_7$	
4552	21968
4579	21839
4583	21818
4619	21649
4652	21732
4686	21340
4707	21245
4972	20112
4985	20060
5028	19888
5064	19747
5091	19642
5099	19611
5131	19489
5162	19372
5188	19275
5198	19238
$Am_2(SO_4)_3$	
4519	22129
4529	22080
4541	22021
4559	21935
4578	21844
4595	21763
4608	21701
4630	21598
4648	21515
4658	21466
4684	21347
4692	21311
5024	19904
5032	19873
5051	19798
5075	19704
5086	19662
5099	19612
5114	19554
5130	19493
5149	19421
5162	19374
5181	19301
5187	19279
5195	19249
$KAm(SO_4)_2$	
4531	22070
4555	21954
4571	21877
4602	21729
4615	21668
4633	21584
4648	21538
4668	21637
4998	20008
5022	19912
5079	19709
5097	19619
5109	19573
5127	19504
5143	19444
5157	19391
5181	19301
$TlAm(SO_4)_2 \cdot 4H_2O$	
4552	21966
4566	21901
4603	21724
4637	21563
4651	21501
5048	19810
5119	19535
5124	19517
5151	19418
5160	19380
$CsAm(SO_4)_2 \cdot 4H_2O$	
4543	22011
4564	21910
4595	21763
4605	21715
4627	21610
4637	21565
4647	21732
5049	19805
5064	19747
5090	19646
5130	19493
5151	19418

TABLE 6

Maximum Peak Separation in the Split Bands at 5030 A for Am^{+++} at 80°K in Crystals of the Compounds Studied (measured between the extremes of the maxima)

Compound	Peak separation of Am^{+++} band at 5030 A (cm^{-1})
$Am_2(SO_4)_3 \cdot 5H_2O$	594
$Am_2(SO_4)_3$	655
$KAm(SO_4)_2 \cdot 2H_2O$	542
$KAm(SO_4)_2$	707
$K_3Am(SO_4)_3 \cdot H_2O$	744
$K_8Am_2(SO_4)_7$	719
$TlAm(SO_4)_2 \cdot 4H_2O$	430
$Tl_8Am_2(SO_4)_7$	715
$CsAm(SO_4)_2 \cdot 4H_2O$	387
$Cs_8Am_2(SO_4)_7$	843

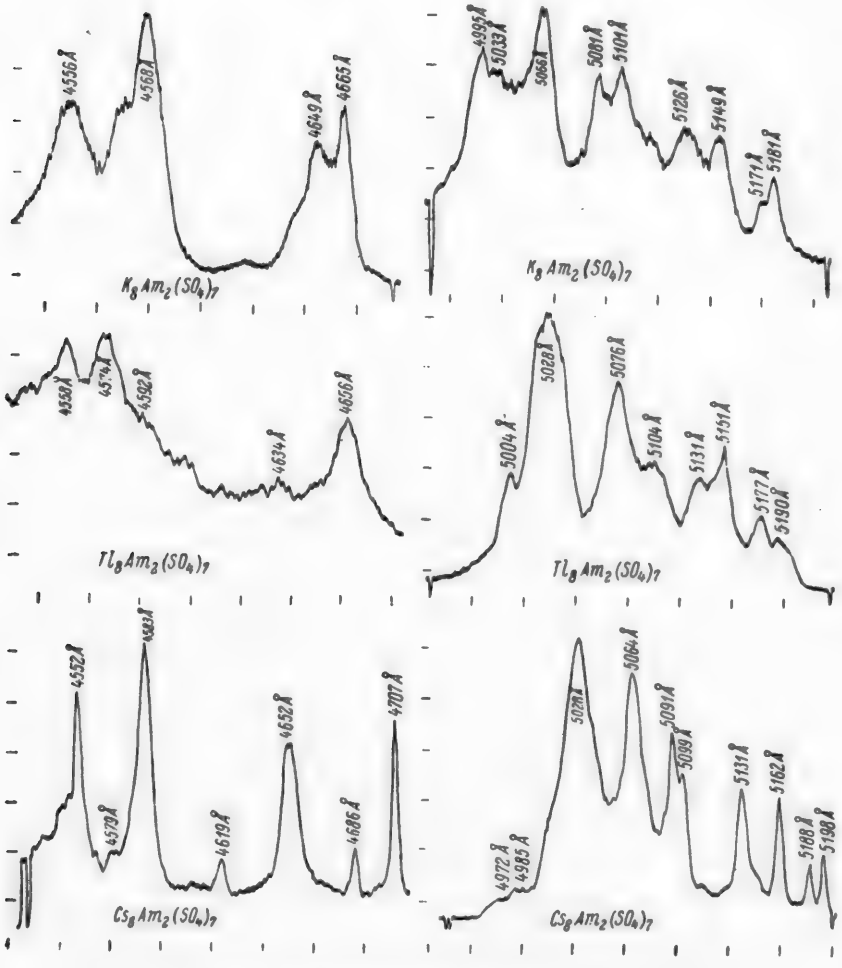

Fig. 7. Absorption spectra of americium compounds at 80°K.

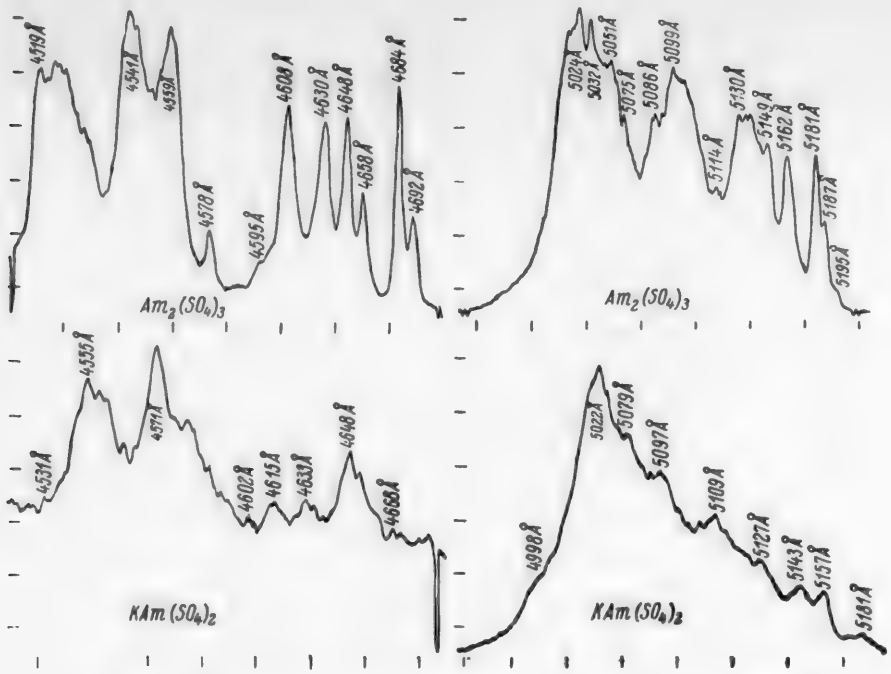

Fig. 8. Absorption spectra of anhydrous americium compounds at 80°K.

actinides differ very little (the radii of the trivalent ions of the uranium-americium series exceed the corresponding values for the neodymium-europium series by 0.03-0.04 A) and also with the fact that the $5f$-electrons of actinides, spatially and energetically, are more subject to extraneous action than are the $4f$-electrons of lanthanides.

Comparison of the data of Table 6 for the different series of compounds discloses certain relationships. The maximum peak separation in the split bands increases on dehydration of the hydrated crystals, probably as a result of the removal of water from the near neighborhood of the absorbing ion and strengthening of the field of the SO_4^{--} groups.

The increase in the total peak separation of the 5030 A band in the $R_8Am_2(SO_4)_7$ series of compounds from potassium and thallium to cesium might be connected with the increasing radius of the monovalent cation (K^+ 1.33; Tl^+ 1.44; Cs^+ 1.67 A) which suggests a maximal interaction (statistical effect) in the case of $Cs_8Am_2(SO_4)_7$. However, as is seen from Fig. 7, the width of the "lines," which characterizes the dynamic effect of interaction of the ion with the lattice, increases toward the $K_8Am_2(SO_4)_7$ side. Possibly in this case a more complex form of interaction takes place leading on the one hand to greater screening of the ion and on the other to an increase in the field that splits, with the result that one of these effects increases at the same time as the other decreases.

The absorption bands of compounds of the composition $R_8Am_2(SO_4)_7$ in the crystalline form consists of four components each of which is subdivided into two. For the bands at 8110 A this secondary splitting is not observed because of the low "dispersing power" of the apparatus in this region. A similar peak separation of the band at 5030 A into four components, as has already been stated, was noted for some americium compounds [9, 11]. Such a band structure allows the assumption that of two energy levels between which transfer takes place, one splits into two and the other into four sub-levels. As a result of transitions between these components, eight separate frequencies are observed.

From the increase in interaction with the environment observed in actinides, as exemplified by americium, the appearance of more intense electronic-vibrational "lines" in these cases would be expected.

In the study of the absorption spectra of americium compounds in the crystalline form, rather intense groups of lines, displaced toward the shortwave side of the electronic band of the order of magnitude of 1500-2000 cm^{-1},

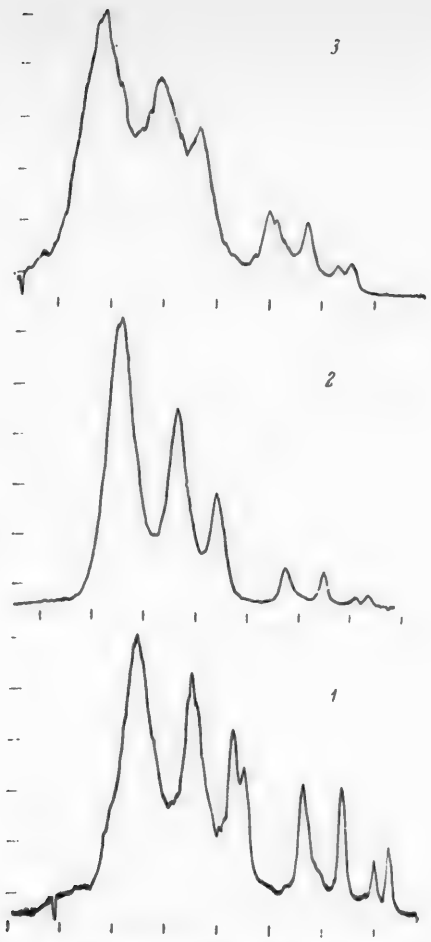

Fig. 9. Peak separation of the Am^{+++} band at 5030 A for $Cs_3Am_2(SO_4)_7$ at various temperatures (°K): 1) 80°; 2) 200°; 3) 300°.

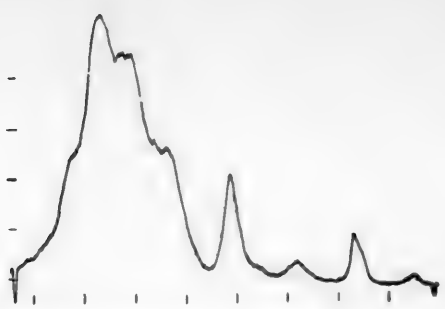

Fig. 10. Absorption spectrum of $Am_2(SO_4)_3 \cdot 5H_2O$ at 80°K in the 4500-A region 15 days after preparation.

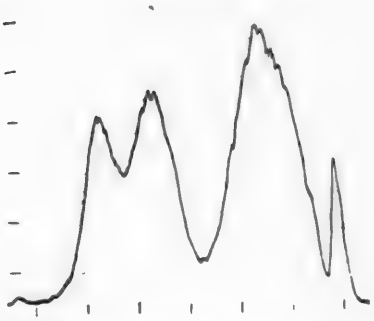

Fig. 11. Peak separation of the Am^{+++} band at 8110 A for $K_3Am_2(SO_4)_7$ at 80°K.

were observed. These lines are most sensitive to changes in composition of the compounds and they repeat in part the structure of the electronic band. It can be surmised that these lines have an electronic-vibrational origin. This is confirmed also by the fact that in the absorption spectrum of the Am^{+++} ion in solution and in crystals of $Am(OH)_3$ (Fig. 4) this group of lines is absent, because the interaction in these cases is evidently small.

Calculation has shown that the differences between the frequencies of these lines and the frequency of the maximum of the 5030 A electronic band do not coincide with the frequencies of the natural vibration of the sulfate ion (990, 1125 and 1340 cm^{-1}) and the water molecule (1640 cm^{-1}), known from Raman spectra data. For example, the following constant differences were found for compounds of the $R_3Am_2(SO_4)_7$ series:

$K_3Am_2(SO_4)_7$	$\Delta\gamma_1$	2021, 2047	(mean	2034 cm^{-1})
	$\Delta\gamma_2$	1502, 1571	(mean	1536 »
$Tl_3Am_2(SO_4)_7$	$\Delta\gamma_1$	2049, 2027	(mean	2038 »
	$\Delta\gamma_2$	1589, 1593	(mean	1591 »
$Cs_3Am_2(SO_4)_7$	$\Delta\gamma_1$	2042, 2080	(mean	2061 »
	$\Delta\gamma_2$	1749, 1761	(mean	1755 »
	$\Delta\gamma_3$	1452, 1498	(mean	1475 »

The noncoincidence of the differences cited with the natural frequencies of the neighboring anions and water molecules is evidently connected with the more complex nature of the americium ion with the lattice, as has already been stated above.

The chemical individuality of all the compounds studied was proved conclusively in the process of plotting the absorption spectra. As stated above, no change was observed in the nature of the absorption spectra of a

preparation on diluting it with varying quantities of potassium sulfate. This fact makes it possible to assert that the absorption spectra obtained relate to individual chemical compounds and not to mixtures of ordinary americium sulfate with potassium, thallium and cesium sulfates.

A quite definite picture of the peak separation of the 5030 A electronic band and a combination of lines at 4500 A was obtained for the compound of each composition.

The identification of a preparation precipitated from solution at one molar ratio of M_R^+/M_{Am}^{+++} or another, was carried out by means of the absorption spectrum; in this way, the phase diagram constructed previously was confirmed and made more accurate. It was found that the upper limit of molar ratios for $K_3Am(SO_4)_3 \cdot H_2O$ lies not at 37.9 but is lower than this. Preparations obtained at ratios of 36, 31, 26 and 24.5 gave an absorption spectrum characteristic of $K_3Am_2(SO_4)_7$ and at ratios of 15, 16.8 and 23.3 – a spectrum characteristic of $K_3Am(SO_4)_3 \cdot H_2O$. A new limit was established as a result of this, lying between 23.3 and 24.5.

There are statements in the literature to the effect that similarity between absorption spectra of crystals bears witness to their isomorphism [10]. Actually, similar spectra are possible only where there are similar crystalline fields which can occur in lattices of the same structure, i.e., in the case of isomorphous compounds.

Comparison of the absorption spectra of the compounds $TlAm(SO_4)_2 \cdot 4H_2O$ and $CsAm(SO_4)_2 \cdot 4H_2O$ enables their isomorphism to be assumed with confidence. The shape of the spectra in the case of compounds of the series $R_3Am_2(SO_4)_7$, of which the double sulfate with cesium was not identified chemically, presents the possibility of drawing the conclusion that they are isomorphous and of assigning the composition $Cs_3Am_2(SO_4)_7$ to this compound. Furthermore, the existence of a double sulfate of the same composition is also possible in the case of rubidium, the ionic radius of which is 1.48 A, close to the ionic radius of potassium, thallium and cesium; however, its preparation may be hindered by the low solubility of rubidium sulfate.

As was expected, very marked changes in the absorption spectra were observed on calcining the compounds $Am_2(SO_4)_3 \cdot 5H_2O$ and $KAm(SO_4)_2 \cdot 2H_2O$. This demonstrates the presence of water of crystallization in them, which evidently enters into the near neighborhood of the americium ion.

The broadening of the lines with temperature rise on Fig. 9 is related to the growth of oscillations in the crystal lattice.

SUMMARY

1. A number of americium compounds have been identified.

2. Phase diagrams have been drawn for the system $R_2SO_4 - Am_2(SO_4)_3 - H_2O$ (R = K, Tl or Rb).

3. The peak separation of the electronic band of Am^{+++} at 5030 A, in crystals of the compounds studied, has been examined.

4. A group of electronic-vibrational "lines" in the 4500 A region, that are not observed in solutions and are very sensitive to changes in composition of the compound, have been identified.

5. The effect of temperature and the presence of water of crystallization on the nature of the peak separation of the electronic band of Am^{+++} at 5030 A and on the combination of electronic-vibrational "lines" in the 4500 A region, has been examined.

6. The electrons of the $5f$-shell interact more strongly with the field of the crystal lattice than do the electrons of the $4f$-shell. This phenomenon could be used successfully in studying the interior structure of crystals.

The authors express their thanks to L.V. Lipis for valuable comments expressed during discussion of this work.

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HYDROGEN EXCHANGE IN PHENOLS, ITS ETHERS AND AROMATIC AMINES WITH LIQUID DBr

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The basic mechanism of deutero-exchange in aromatic hydrocarbons dissolved in liquid DBr has been established earlier [1, 2]. In this communication, results are reported from a study of hydrogen exchange with liquid DBr in aromatic compounds with substituents containing a hydrogen or nitrogen atom.*

The free electron pairs of the hydrogen or nitrogen atom of the substituent interact with the π-electrons of the aromatic ring as a result of which the electron density of the ortho and para atoms of the hydrocarbon is increased (π-conjugation, p-effect, see [4]). The addition of a proton (deuteron) to the electron pair of the nitrogen or hydrogen atom can bring about their transition to the four- or three-valent positively charged ions, respectively. These characteristics of the compounds mentioned determine the specific nature of their deutero-exchange with acids.

Hydrogen exchange in the compounds in which we are interested (with the exception of $C_6H_5OC_6H_5$) has been studied by a number of authors, but under conditions differing from ours. Small and Wolfenden [5] found that on heating phenol with D_2O at 100° slow exchange of hydrogen in the ring takes place. Acids accelerate the exchange considerably. Ingold and co-workers [6] and Koizumi [7] showed that the exchange is of the electrophilic substitution type. The ortho and para hydrogen atoms take part in the exchange [8]. These same hydrogen atoms rapidly undergo exchange with gaseous DCl [9]. A.J. Brodskii, G.P. Miklukhin and their collaborators [10] studied the bimolecular reaction between hydroxy groups and the phenolic nucleus.

Deutero-exchange in anisole proceeds slowly with aqueous DCl but more rapidly with D_2SO_4 [6] and with glacial acetic acid (on catalysis with sulfuric acid) [11]. Exchange of three H atoms of the nucleus was achieved. Exchange of the ortho and para H atoms of the dimethylamine and aniline nuclei with aqueous DCl and D_2SO_4 proceeds more rapidly than is the case with phenol [6, 8].

Kharasch and Brown [12] found that the ortho and para H atoms of triphenylamine, diphenylamine and dimethylaniline exchange with C_2H_5OD on catalysis with D_2SO_4 at 100° for 100 hours.

EXPERIMENTAL

The apparatus for the preparation of liquid DBr and the method of carrying out deutero-exchange experiments has been described previously [13]. The exchange experiments were carried out usually at 20-25°. The number of hydrogen atoms "n" in aromatic compounds that are exchanged for deuterium, with concentrations of deuterium in HBr of less than 5 atoms %, was calculated according to Equation (10) (see [14]), and with concentrations > 80 atoms % – according to the equation $n = c_w N/c_s^0$ (1), where: $\underline{c}$ is the concentration of D in atoms % in the water of combustion of the materials and c_s^0 – in the hydrogen bromide, and N is the number of hydrogen atoms in the compound. Experiments on the reverse exchange were worked out according to Equation (11) (see [14]). $\underline{c}$ was determined by means of a spot method with an accuracy of up to 0.02-0.05 atoms %. In the case of high D concentrations the water from the combustion of the compounds was diluted by weight with water of normal isotopic composition. All the compounds studied were carefully purified and dried before carrying out the experiments. The weight of substance taken was usually 0.2-1.0 g and of solvent, 15-20 g.

*Results of papers presented at the All-Union Conference on the Use of Isotopes [3]. The investigation of phenol and its ethers was part of the dissertation of A.V. Vedeneev Karpov (Phys.-Chem. Inst. (1955)).

Compounds. Phenol, "Pure for Analysis," was twice redistilled in vacuo in a current of dry nitrogen. The second distillation was carried out over anhydrous $CuSO_4$; m.p. 40.5-41°. Anisole, "pure," was fractionated in vacuo and dried over metallic sodium; b.p. 153.5°, $n^{20}D$ 1.5170. Dimethylaniline was steam-distilled, solidified by cooling, dried over metallic sodium and redistilled in vacuo, b.p. 192.5°, $n^{20}D$ 1.5583. Diphenylamine and triphenylamine were distilled in vacuo. Their melting points were 53.5 and 125.5°, respectively.

All the compounds are readily soluble in DBr, form colorless solutions and can be isolated unchanged from solution. The latter was shown by determination of the constants after exchange experiments. The phenol solution after 24 hours acquired a crimson, then violet, color. The anisole solution also behaved in the same way after 17 hours. On prolonging the experiments with phenol the quantity isolated was reduced. In experiments lasting more than 150 hours phenol could not be isolated. Anisole was even less stable. After 17 hours the anisole had been converted to phenol. The reaction evidently proceeds according to the equation $C_6H_5OCH_3 + HBr \rightarrow$ $\rightarrow C_6H_5OH + CH_3Br$. Phenol was identified by conversion to tribromophenol.

In order to terminate the deutero-exchange reaction the sealed glass tubes were plunged into liquid air. After this the DBr was evaporated off. The residue was extracted with ether. In the cases of dimethylamine and diphenylamine, which form the corresponding hydrobromides, aqueous alkali was added beforehand. The ethereal extracts were next dried over potassium carbonate (phenol, diphenylamine, dimethylaniline) and the ether was distilled off. In experiments with diphenylamine, in order to liberate deuterium in the NH group, the ethereal extract was extracted several times with water of the normal isotopic composition. After evaporation of the ether the materials were twice redistilled in vacuo (anisole, diphenyl ether and dimethylaniline over metallic sodium). After this treatment the constants of the materials showed no further change.

Already the first experiments with phenol, anisole, diphenyl ether and triphenylamine showed that hydrogen exchange with DBr proceeds very rapidly. Hence the exchange reaction equilibrium could be set up during the time of evaporation of the DBr, i.e., at a temperature of approximately −60° [14]. The values of the distribution coefficients which are necessary for the calculation of the number of hydrogen atoms exchanged, according to Equation (10) (see [14]), are known only approximately ($a \sim 5$) [15]. Consequently, the exchange experiments with C_6H_5OH, $C_6H_5OCH_3$, $(C_6H_5)_2O$ and $(C_6H_5)_3N$ had to be conducted with DBr containing 80-100 atoms % of D. In these circumstances n could be calculated approximately by Equation (1).

In the tables given below the following designations are used: T is the duration of experiment; t° is the temperature; m_c is the number of moles of compound; m_s is the number of moles of solvent; m_{AlBr_3} is the number of moles of $AlBr_3$ catalyst; c_s^0 is the concentration of deuterium in the solvent at the beginning of the experiment, in atoms %; c_w is the concentration of dueterium in the water of combustion of the compound at the end of the experiment; n is the number of atoms of deuterium (protium) exchanged; k is the rate constant of the hydrogen-exchange reaction, calculated according to the first-order reaction equation.

Hydrogen exchange in phenol (Table 1). Four of the hydrogen atoms in phenol are exchanged for deuterium very rapidly. One of these is that of the hydroxyl group and three deuterium atoms become attached to the ortho and para positions of the nucleus. This was verified by two methods. First the phenol after deuterization was brominated to 2,4,6-tribromophenol and the deuterium was removed from the hydroxyl group by washing with water of the normal isotopic composition. The water obtained from combustion of the tribromophenol was almost free of deuterium. Second, by heating phenol with heavy water in the presence of alkali, 2,4,6-trideuterophenol [6] was obtained. The reverse exchange of these materials with HBr was then carried out.

As is seen from Table 2, only a small quantity of deuterium [$c_{w\,(calc)}$] remained in the phenol after this, the amount of deuterium corresponding to the ratio of the compound and solvent allowing for the coefficient of distribution of deuterium a between the bonds C−H and H−Br.*

Hydrogen exchange in anisole (Table 1). The three hydrogen atoms in the ortho and para positions in the nucleus exchange very rapidly. This was shown in the following way. 2,4,6-Trideuterophenol, prepared as described above, was methylated with dimethylsulfate. The 2,4,6-trideuteroanisole was then treated with liquid HBr. The results (Table 2) indicate that the ortho and para atoms undergo exchange.

*As is seen from Table 1, in all experiments with phenol for exchange of H in the nucleus a value of $n < 3$ was obtained. The reason for this is not clear to us.

TABLE 1

Isotopic Hydrogen Exchange in Phenol, Anisole and Diphenyl Ether

Expt. No.	T	t°	c_S^0	c_W	n	$\frac{m_{AlBr_3}}{m_W}$
			Phenol			
1	10 min	Room	91.0	53.0	3.5	
2	30 »	25	91.0	55.1	3.6	
3	3 hours	25	91.0	53.1	3.5	
4	27 »	Room	91.0	55.0	3.6	
5	72 »	»	88.8	37.3	2.5 *	
6	150 »	»	88.8	39.0	2.6 *	
			Anisole			
7	5 min	Room	93.7	32.9	2.8	
8	10 »	»	90.9	35.1	3.1	
9	30 »	25	90.9	33.8	3.0	
10	3 hours	25	93.7	33.9	2.9	
11	6 »	25	93.7	31.2	2.7	
12	5 min	Room	83.5	42.0	4.0	0.9
13	30 »	25	93.7	43.6	3.7	0.8
			Diphenyl ether			
14	10 »	Room	90.9	55.0	6.0	
15	3 hours	25	90.9	55.0	6.0	
16	24 »	Room	88.8	54.3	6.1	
17	26 »	»	90.9	55.9	6.1	
18	150 »	»	88.8	51.8	5.8	
19	313 »	»	93.7	57.3	6.1	
20	1 »	25	100	83.4	8.3	1.3
21	1 »	25	100	90.9	9.0	0.5
22	3 »	25	100	95.4	9.5	1.0

*Deuterium was washed out from the hydroxyl with water of normal isotopic composition.

Experiments were set up to examine the effect of addition of $AlBr_3$ on the rate of hydrogen exchange. As is known, $AlBr_3$ markedly increases the acidity of solutions in liquid DBr. As is seen from the data of Table 1 (experiments 12 and 13), the presence of $AlBr_3$ brings about additional exchange beyond three atoms (evidently, in the meta position). Unfortunately, after only one hour in the presence of $AlBr_3$ anisole undergoes irreversible changes and its isolation is impossible (in an analogous experiment with phenol the latter could not be isolated after being acted upon by $AlBr_3$ for only five minutes).

Hydrogen exchange in diphenyl ether (Table 1). Six hydrogen atoms exchange very rapidly. It is natural to assume that these are the ortho and para hydrogen atoms. In order to verify this assumption, decadeuterodiphenyl ether was prepared by exhaustive deuterization of diphenyl ether in a solution of potassium amide in ND_3. On carrying out the reverse exchange of decadeuterodiphenyl ether with liquid HBr (Table 2) in ether, only an amount of deuterium corresponding to four deuterium atoms were left, remaining in the meta positions in the nucleus. It was not possible to exchange more than six atoms with liquid DBr even in experiments lasting 300 hours. However, increasing the acidity of the solution by addition of $AlBr_3$ resulted in all ten hydrogen atoms being exchanged in only three hours. Therefore, the meta atoms also took part in the exchange.

Hydrogen exchange in triphenylamine, diphenylamine and dimethylaniline (Table 3). In triphenylamine nine hydrogen atoms undergo exchange in five minutes. Further exchange was not observed even after 200 hours. On addition of $AlBr_3$ the rate of hydrogen exchange is markedly reduced (Table 3, experiments 5-7). During five minutes instead of nine hydrogen atoms, less than one is exchanged.

Hydrogen exchange proceeds considerably more slowly in diphenylamine than in triphenylamine. The exchange of six hydrogen atoms could be effected only after 1000 hours. The addition of $AlBr_3$ gave no marked effect on the rate of hydrogen exchange (experiment 9).

TABLE 2

Experiments on Reverse Exchange With Liquid HBr at 25°

Expt. No.	τ (min)	$\frac{m_s}{m_w}$	c_w^0	c_w	c_w^* (calc)
		2,4,6-D-phenol			
1	5	50	3.23	1.04	0.7
2	5	48	3.23	1.22	0.8
3	30	32	3.23	1.14	0.9
		2,4,6-D-anisole			
4	5	80	2.27	0.55	0.55
5	5	59	2.27	0.65	0.63
6	30	38	2.27	0.77	0.77
		Decadeuterophenyl ether			
7	10	150	8.84	4.32	4.64
8	10	230	8.84	4.15	4.24

*c_w (calc) is the calculated concentration of deuterium in the water from the combustion of the substances after the experiment. The number of exchangeable atoms for phenol and anisole was taken as 3, for diphenyl ether as 6, and the distribution coefficient a, as 5.

Hydrogen exchange in dimethylaniline was practically absent even in experiments lasting more than 1100 hours. The presence of $AlBr_3$ had no effect on the rate of deutero-exchange (experiment 17).

DISCUSSION OF RESULTS

In phenol and its ethers, deutero-exchange proceeds in a similar manner. The ortho and para hydrogen atoms of the nucleus exchange very rapidly but further exchange was not observed even over a long period of time. Such a rapid exchange of the nuclear hydrogen atoms is evidently explained by the increased electron density in the ortho and para positions as a result of the π-conjugation p-effect. According to A.N. Nesmeianov's terminology [4], transference of the reaction center from the hydrogen atom to a ring carbon atom in the ortho or para position takes place. How strongly the exchange reaction is accelerated as a result of the π-conjugation p-effect is seen by comparison of the rates of hydrogen exchange of phenol, anisole and diphenyl ether with the corresponding hydrocarbons. In benzene the exchange proceeds extremely slowly ($k_{20°} = 5 \cdot 10^{-8}$ sec^{-} [1]); in toluene and diphenyl, exchange of the para and ortho atoms proceeds much more rapidly ($k_{25°} = 10^{-4}$-10^{-5} sec^{-1}) [1, 2].

How much the rate of hydrogen exchange depends on the acidity of the deuterizing agent is seen from the fact that on heating phenol for 400 hours at 100° only two nuclear hydrogen atoms are exchanged [5] and anisole does not take part in an exchange reaction with heavy water.

Hydrogen exchange in aromatic amines with liquid DBr, in contrast to phenol and its ethers, proceeds quite differently. In triphenylamine nine atoms exchange extremely rapidly. While in dimethylaniline deutero-exchange did not occur even in experiments carried on for more than 1100 hours. Diphenylamine, in which six hydrogen-exchange atoms are exchanged very slowly, occupies an intermediate position.

According to Karasch [12] all three of the above-mentioned amines exchange the ortho and para nuclear hydrogen atoms in C_2H_5OD on catalysis with D_2SO_4 (at 100° and an acid concentration of 0.6 N).

The different behavior of the aromatic amines in hydrogen exchange must be ascribed to their dissimilar basicities. As is known, the basicity falls in the order: dimethylaniline > diphenylamine > triphenylamine. Whereas dimethylamine forms a very stable salt with DBr, triphenylamine does not give a salt with DBr. Diphenylamine is intermediate between the two.

TABLE 3

Isotopic Exchange in Triphenylamine, Diphenylamine and Dimethylaniline

Expt. No.	τ	$t°$	$\frac{m_S}{m_W}$	$\frac{m_{AlBr_3}}{m_W}$	c_S^0	c_W	n
			Triphenylamine				
1	5 min	Room			83.5	48.8	8.8
2	2 hours	25			88.8	51.2	8.7
3	2 »	25			83.9	47.5	8.5
4	200 »	Room			93.7	52.5	8.4
5	5 min	»		1.2	93.7	3.1	0.5
6	5 »	»		1.0	~100	2.6	0.4
7	5 »	»		0.4	~100	27.4	4.1
			Diphenylamine				
8	1 hours	25	100		5.4	0.2	0.1
9	1 »	25	140	0.5	5.4	0.2	0.1
10	2 »	25	90		88.8	2.6	0.3
11	24 »	Room	140		9.0	2.0	1.1
12	97 »	»	140		9.0	6.6	3.9
13	120 »	»	74		4.4	4.0	5.2
14	696 »	»	59		4.4	4.7	5.6
15	1152 »	»	110		4.4	5.3	6.0
			Dimethylaniline				
16	1 hours	25	50		5.4	0.1	~0
17	1 »	25	51	0.3	5.4	0.1	~0
18	696 »	Room	91		4.4	0.1	~0
19	1152 »	»	97		4.4	0.1	~0
20	1152 »	»	63		4.4	0.02	~0

On dissolving dimethylaniline in liquid DBr a deuteron adds on to the free electron pair of the nitrogen atom which becomes tetravalent.

The conjugation of the p-electrons with the π-electrons of the nucleus is disrupted and the ortho and para carbon atoms cease to be negatively charged. Consequently, a deuteron cannot add on to them, which is the necessary condition for hydrogen exchange in an acid medium. The failure of dimethylaniline to undergo exchange is possibly explained also by the fact that this substance forms a positively charged ion, the addition of a deuteron to which is hindered.

In triphenylamine, where no salt is formed, on the other hand the π-conjugation p-effect is fully manifested and exchange with the strongly acidic DBr takes place rapidly. Although diphenylamine forms a salt with the acid the π-conjugation p-effect is nevertheless appreciable, inasmuch as slow deutero-exchange of the ortho and para hydrogen atoms takes place. This result confirms that acid-base interaction does not certainly lead to complete transfer of a proton (deuteron) of the acid to the base [16].

It was of interest to examine whether it is possible, by still further increasing the acidity of the solution, to eliminate the action of the π-conjugation p-effect, as occurs in the case of dimethylaniline. It was found that $AlBr_3$ markedly retards the rate of hydrogen exchange in triphenylamine. On addition of the stoichiometric quantity of $AlBr_3$ to triphenylamine, in five minutes less than one hydrogen atom undergoes exchange instead of nine. Evidently, addition of $AlBr_3$ increases the acidity of the medium to such an extent that a deuteron is added on to the free pair of p-electrons of the nitrogen atom with formation of the salt $(C_6H_5)_3ND^+AlBr_4^-$. It is possible, also, that $AlBr_3$ coordinates with the nitrogen atom. A.V. Topchiev [17] found that the addition of BF_3 to the nitrogen atom of aniline in nitration of the latter, sharply reduces the yield of the ortho and para isomers. As is seen from the data of Table 3 (experiment 7), if $AlBr_3$ is added in a quantity less than equimolecular the rate of exchange is higher. This result is quite understandable inasmuch as only a part of the triphenylamine molecule forms a salt (or coordinates with $AlBr_3$).

Addition of $AlBr_3$ to diphenyl ether and anisole not only does not decrease, but on the other hand increases the rate of hydrogen exchange. This indicates that neither formation of the corresponding oxonium salt nor coordination of $AlBr_3$ with a hydrogen atom takes place.

The different behavior with respect to hydrogen exchange of phenol and its ethers on the one hand and aromatic amines on the other is explained by the dissimilar coordinating power and different affinity for a proton of the hydrogen and nitrogen atoms. It is sufficient to recall only that in aqueous solution phenol is a weak acid and aniline reacts as a weak base.

SUMMARY

1. Hydrogen exchange in phenol and its ethers ($C_6H_5OCH_3$, $C_6H_5OC_6H_5$) and in aromatic amines ($C_6H_5N(CH_3)_2$, $(C_6H_5)_2NH$, $(C_6H_5)_3N$) with liquid DBr and also with DBr + $AlBr_3$ at 25° has been studied.

2. In all the compounds of the first group the ortho and para hydrogen atoms exchange instantaneously, but in the second group of compounds rapid exchange is observed only in $(C_6H_5)_3N$, whereas in $(C_6H_5)_2NH$ exchange of the atoms mentioned proceeds very slowly, and in $C_6H_5N(CH_3)_2$ it is not observed even after 1000 hours. $AlBr_3$ brings about exchange of the meta atoms in the phenyl ethers and retards the exchange reaction rate in $(C_6H_5)_3N$.

3. The specific nature of deutero-exchange in aromatic compounds with substituents containing hydrogen or nitrogen atoms is explained by the π-conjugation p-effect. The difference in behavior with respect to hydrogen exchange with liquid DBr and DBr + $AlBr_3$ of substances containing hydrogen and nitrogen is connected with their dissimilar affinities for a proton and the difference in coordinating power of the hydrogen and nitrogen atoms.

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HYDROGEN EXCHANGE OF PHENOL AND ITS ETHERS WITH SOLUTIONS OF POTASSAMIDE IN LIQUID DEUTEROAMMONIA

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In a previous communication [1] it was shown that the hydrogen-exchange capacity of phenol and its ethers and aromatic amines with liquid DBr is explained by the effect of p,π-conjugation and these reactions are affected by the different proton affinities and coordinating capacities of the oxygen and nitrogen atoms of the substituents in these compounds.

In this report we describe results obtained in studying the hydrogen exchange of phenol and its ethers with solutions of KND_2 in liquid ND_3. They supplement our ideas on the mutual effect of the atoms in molecules of the given substances and lead to certain conclusions on the mechanism of hydrogen exchange.*

EXPERIMENTAL

The procedure was described previously [2]. Particular attention was paid to drying the apparatus, the starting materials and the solvents since potassamide reacts readily with moisture. The operations connected with taking samples were either performed in a special "dry" box or in a stream of dry nitrogen. The samples of material were usually 0.2-0.5 g and of solvent, 3-5 g. At temperatures up to 40°, the experiments were performed in glass ampoules and at higher temperatures, in stainless-steel ampoules. The preparations of phenol, anisole and diphenyl ether were the same as in the work with liquid DBr [1]. n, the number of hydrogen atoms exchanged for deuterium, was calculated by the formula

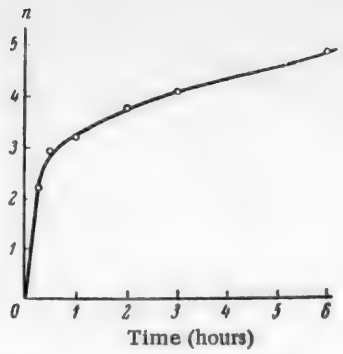
$$n = \frac{c_w \cdot H}{\alpha \left[c_w^0 - \frac{\alpha \cdot H \cdot H_0 \cdot m_w}{H_s \cdot n_t \cdot m_s} \right]},$$

where: c_w and c_s^0 are the D concentrations in at.% in water from combustion of the substance and the solvent before the experiment; α is the distribution coefficient of deuterium between the N–H and C–H bonds and equals 0.92 [3]; H is the number of hydrogen atoms in the substance; H_0 is the number of exchangeable hydrogen atoms in the substance; H_s is the number of exchangeable hydrogen atoms in the solvent; n_t is the number of hydrogen atoms in the substance, exchanged up to the given moment of time, calculated by the formula $n_t = \frac{c_w \cdot H}{\alpha c_s^0}$; m_w is the number of moles of substance and m_p the number of moles of solvent.

The rate constants of hydrogen exchange were calculated from a first-order equation.

Hydrogen exchange in phenol. In the first approximation, we neglected the ammonolysis of potassium phenolate, formed by reaction with KND_2, and considered that the solution of the phenol consumed an equivalent amount of amide. At the end of the deuterium-exchange experiment, the reaction mixture was poured into dilute HCl solution. The phenol was extracted with ether, the ether solution dried with baked Na_2SO_4 and the phenol vacuum distilled twice. After the experiments the phenol had m.p. 40.5-41°. The results of the experi-

*The results were presented at the conference on the use of isotopes in April 1957. They are from the dissertation of A.V. Vedeneev [Karpov Phys. Chem. Inst. (1955)].



Hydrogen-exchange kinetics of anisole in a 0.03-N solution of KND_2 in ND_3 at 25°.

ments are shown by the data in Table 1. The symbols used in the tables are the same as in the previous communication [1]; c_{KND_2} is the concentration of potassamide in the solution (N) and c_W^1 the concentration of D in at. % in water from combustion of tribromophenol.

The fact that hydrogen exchange in the phenolate ion proceeds very slowly attracts attention. Heating for 200 hours at 120° was required to exchange all the hydrogen atoms. This is explained by the fact that the ring of the phenolate ion is negatively charged and the approach of the ND_2^- ion (a condition of exchange) is hindered. If the effect of p,π-conjugation played a determining role in the exchange of the phenolate ion with a solution of KND_2 in ND_3, then the first hydrogens to exchange should be those in the meta-positions, i.e., the positions with the lowest electron density. To test this hypothesis, experiments 5, 6 and 8 (Table 1) were stopped when, on a statistical average, about 1 hydrogen atom had exchanged. The phenolate was converted into phenol and the latter into 2,4,6-tribromophenol. If the meta H atoms were to be first to exchange, then the concentration (c_W^1) from combustion of the tribromophenol would be higher than that (c_W) from combustion of the phenol. If the ortho and para H atoms were to exchange, then $c_W^1 = 0$.

As the data in Table 1 show (last column), $c_W^1 < c_W$. This may be interpreted as meaning that all the H atoms in $C_6H_5O^-$ exchange with approximately the same probability. Evidently, under the action of a very strong base, the differences in "acidity" of the hydrogen atoms of the aromatic ring are leveled out, as usually occurs with acids that are dissolved in protophilic solvents [4].

A comparison of the rate of H-atom exchange in the phenolate ion and benzene showed that at c_{KND_2} = = 0.4 N, $k_{50°} = 5 \cdot 10^{-6}$ and $8 \cdot 10^{-3}$, respectively (calculated data from [5]), i.e., the reaction of the phenolate ion is three orders slower.

TABLE 1

Hydrogen Exchange in Phenol: $c_{KND_2} = 1.19$ N; $c_S^0 = 9.10$ at %

Expt. No.	τ (hrs)	t°	$c^*_{KND_2}$	$\frac{m_S}{m_W}$	$\frac{m_{KND_2}}{m_W}$	α_W	n	c_W^1
1	1	25	0.20	33	0.19	0.12	0.1	
2	12	25	0.46	49	0.64	0.21	0.2	
3	6	50	0.37	43	0.27	0.60	0.4	
	16	~20						
4	8	50	0.20	44	0.24	0.90	0.6	
5	9	50	0.41	45	0.53	1.01	0.7	0.49
6	8	50	0.37	46	0.48	1.07	0.8	0.46
7	75	35	0.43	47	0.57	1.55	1.1	
8	19	50	0.40	45	0.51	2.04	1.5	1.03
	27	20						
9	221	100	0.53	54	0.42	5.90	4.3	
10	201	120	0.79	88	1.97	6.50	4.8	

Hydrogen exchange in anisole. A solution of anisole in ND_3 + KND_2 had a yellow-green color. To stop the exchange reaction, the reaction mixture was cooled to −70°. When the ammonia had been distilled away at low temperature, the anisole was vacuum distilled over anhydrous copper sulfate, which bound the ammonia residues. In experiments lasting more than a day, evaporation of the ammonia left a gelatinous mass, from which the anisole was extracted with absolute ether. After this treatment, the constants of the anisole remained unchanged. The results obtained are presented in Table 2. All the H atoms in anisole could be exchanged.

TABLE 2

Hydrogen Exchange in Anisole: $c_{KND_2} = 0.028$ N

Expt. No.	τ	$t°$	$\frac{m_S}{m_W}$	$\frac{m_{KND_2}}{m_W}$	c_S^0	c_W	n
1	15 min	25	184	0.14	4.38	1.03	2.1
2	15 »	25	61	0.05	4.38	1.11	2.3
3	30 »	25	49	0.04	4.38	1.31	2.8
4	30 »	25	40	0.04	9.46	3.10	3.0
5	1 hours	25	40	0.03	4.38	1.48	3.2
6	1 »	25	47	0.04	4.38	1.53	3.2
7	2 »	25	48	0.04	4.38	1.77	3.8
8	3 »	25	41	0.03	4.38	1.87	4.1
9	3 »	25	43	0.03	4.38	1.95	4.1
10	6 »	25	44	0.03	4.38	2.33	4.9
11	6 »	25	85	0.06	4.38	2.42	5.0
12	22 »	~20	41	0.03	4.38	2.75	5.9
13	89 »	~20	40	0.03	9.46	6.55	7.0
14	144 »	~20	47	0.01	9.46	7.66	7.6

The extent of their nonequivalence is indicated by the kinetic curve (see the figure). To establish the sequence in which the H atoms exchange in anisole, preparations labeled in different positions were synthesized.

2,4,6-Trideuteroanisole was prepared by a dimethyl-sulfate methylation of 2,4,6-trideuterophenol, prepared by isotope exchange of hydrogen in phenol with a solution of alkali in D_2O [6].

Pentadeuteroanisole, $C_6D_5OCH_3$ was prepared by isotope exchange with DF.*

Then the number of D atoms left after treatment of these preparations with KNH_2 in NH_3 was determined. The results are presented in Table 3.

TABLE 3

Experiments on the Reverse Exchange With Deuterated Anisole Preparations at 25°

Expt. No.	c_S^0	Number of D atoms	c_{KNH_2}	τ	$\frac{m_S}{m_W}$	c_W	Number of D atoms left	Number of D atoms replaced
				2,4,6-Trideuteroanisole				
1	2.27	2.7	0.03	5 min	60	0.87	1.0	1.7
2		3.0	0.10	5 »	51		1.0	2.0
3	2.27	2.7	0.04	30 »	66	0.77	1.0	1.7
4	2.27	2.7	0.04	30 »	50	0.77	1.0	1.7
5	2.27	2.7	0.03	30 »	63	0.74	1.0	1.7
6	2.27	2.7	0.04	1 hr	71	0.77	1.0	1.7
7	2.27	2.7	0.03	6 »	56	0.44	0.6	2.1
				2,3,4,5,6-Pentadeuteroanisole				
8	2.66	4.7	0.03	30 min	52	1.29	2.5	2.2
9	2.66	4.7	0.03	6 hr	60	0.28	0.6	4.1
10	2.66	4.7	0.03	6 »	58	0.26	0.5	4.2

*Experiments on the exchange with HF and DF were performed together with Ia.M. Varshavskii, to whom we are grateful.

Comparison of the results shows that the ortho D atoms exchange very rapidly, then the meta atoms and finally the hydrogen in the para position. These data agree with the conclusions of Roberts, et al. [7]. By measuring the rate of D exchange in isomers of monodeuteroanisole with a solution of KNH_2 in NH_3 at −33.5°, they obtained the following values for the rate constants (sec^{-1}) for exchange of ortho, meta and para atoms: $9 \cdot 10^{-4}$, $1 \cdot 10^{-7}$, $1 \cdot 10^{-8}$. Deuterium exchange in monodeuterobenzene proceeds at a rate of $\sim 10^{-7}$ sec^{-1}.

To compare the rate of exchange of hydrogen in the methoxy group with that of the H atoms in the ring that are substituted most slowly – the para atoms – we used preparations of trideuteroanisole and 4-monodeuteroanisole.

Trideuteroanisole, $C_6H_5OCD_3$, was prepared by exhaustive exchange with a solution of KND_2 in ND_3 with subsequent treatment with HF.*

4-Monodeuteroanisole, $C_6H_4DOCH_3$, was prepared from 2,4,6-trideuteroanisole by two treatments (at room temperature for ten minutes) with a 0.03-N solution of KNH_2. Under these conditions only the ortho H atoms exchanged and the para atom was hardly involved.

The rate of exchange of the para H atom in the ring ($3 \cdot 10^{-4}$ sec^{-1}) was twice as great as in the methoxyl group ($\sim 1.4 \cdot 10^{-4}$ sec^{-1}) (Table 4). Comparison of the rate of exchange of the para H atom in anisole with that of the H atoms in benzene shows that at $c_{KND_2} = 0.27$ N, $k_{25°} = 3 \cdot 10^{-4}$ and $6 \cdot 10^{-4}$, respectively (recalculated data from [5]). Thus, the exchange of a hydrogen in benzene proceeds approximately twice as fast as in the para position of anisole. The methoxyl group exchanges approximately four times more slowly than H atoms in benzene.

TABLE 4

Kinetics of Reverse Exchange: $c_{KNH_2} = 0.27$ N, 25°

Expt. No.	c_w^0	τ (hours)	$\frac{m_s}{m_w}$	c_w	$k \cdot 10^{-4}$ (sec^{-1})
			$C_6H_5OCD_3$		
1	3.27	1.0	105	2.08	1.3
2	3.27	1.5	127	1.58	1.3
3	3.27	1.5	160	1.53	1.4
4	3.27	2.0	168	1.11	1.5
			4 - Monodeuteroanisole		
5	3.21	0.5	135	1.85	3.1
6	3.21	0.66	190	1.48	3.2
7	3.21	0.66	127	1.58	2.9
8	3.21	1.0	185	1.05	3.1
9	3.21	1.0	150	1.05	3.1
10	3.21	1.5	170	0.66	2.9

If we assume that the effect of conjugation plays the main role in the exchange of hydrogen in anisole with solutions of KND_2 in ND_3, then we would expect a completely different sequence of hydrogen exchange in the ring than that observed, namely, meta > para, ortho. The actual decrease in H-exchange rate in the anisole ring is in the order ortho > meta > para and compels us to assume that the determining effect in hydrogen exchange in anisole with solutions of $KND_2 + ND_3$ is the inductive effect of the oxygen atom.

In work from our laboratory, the strong analogy between deuterium-exchange reactions with nucleophilic reagents and metallation reactions has been stressed repeatedly [8, 9]. What is known about the metallation of anisole?

Wittig et al. [10] established that in the metallation of dimethylaniline, anisole and fluorobenzene with

*It was established experimentally (together with Ia.M. Varshavskii and M.G. Lozhkina) that only the ring H atoms of anisole exchange with liquid DF and those of the methoxyl group are not involved. The experiments will be described later.

phenyllithium, only the ortho-H atoms were substituted and the rate of metallation increased in the order given. Wittig explained these results by the fact that the electronegativities of the heteroatoms attached to the ring (N, O and F) increased in the same order. Since the inductive effect is rapidly attenuated along a chain of carbon atoms, the ortho-H atoms will be protonized more readily than the other atoms. It is for just this reason that a metal replaces only the ortho atoms and the rate of metallation increases in the given order. Roberts [7] showed that the rule noted by Wittig was also observed in hydrogen exchange with solutions of potassamide in liquid ammonia in isomers of monodeuterofluorobenzene and deuteroanisole. The rate constants of the reverse exchange of D in o-, m- and p-monodeuterofluorobenzenes were equal to $4 \cdot 10^{-1}$, $4 \cdot 10^{-4}$ and $2 \cdot 10^{-5}$ sec^{-1}, respectively. Due to the high electronegativity of the fluorine atom in comparison with oxygen, in the case of fluorobenzene, the absolute value of the constant was higher than in the case of anisole.

Of the results that we obtained, we should note particularly the fact that it was possible to exchange all eight H atoms in anisole, including those in the methoxyl group. This fact* was already established in 1950 [11]. Thus, the aromatic ring affects the lability of the H atoms in the C—H bonds, separated by an oxygen atom. This is also confirmed by experiments with methoxynaphthalene [14]. This phenomenon is even more widespread: the effect of the aromatic ring on an aliphatic bond is also transmitted by a nitrogen atom. This follows from the complete exchange of hydrogen in dimethylaniline and dimethylnaphthalene [11].

In connection with the above, it was also interesting to compare the exchange of hydrogen in toluene and anisole with solutions of $KND_2 + ND_3$. In contrast to anisole, the hydrogen atoms in the methyl group of toluene [12] exchanged considerably more rapidly (~250 times) than those in the ring. The acidity of the H atoms of the methyl group of toluene is sufficient for them to be substituted by cesium [13].

What is the reason for the exchange of hydrogen in the OCH_3 group of anisole? In analogy with the σ,π-conjugation effect (for example, in toluene), the effect of the ring on the mobility of the hydrogen atoms of the CH_3O group may be considered as a π,p,σ-conjugation effect. There is an indication of this in the review article by Wiles [14]. He notes that with such conjugation present, the C—O bond in the anisole molecule must be shortened; this is confirmed by x-ray data. In the opinion of the author, one should be rather careful in interpreting these data.

It is quite possible that in this case the determining role is played by an inductive displacement of the electrons at the oxygen atom, facilitating the protonization of H atoms in the methoxyl group. This hypothesis is supported by the results of experiments by Lauer and Day [15] on the exchange of deuterium, introduced chemically into the position para to the alkoxyl group in phenyl alkyl ethers. The solvent was glacial acetic acid and the catalyst, H_2SO_4. It was found that the rate of electrophilic replacement of the para-D atom in the aromatic ring increased in an order corresponding to the inductive effect of the alkyl group, namely: $CH_3(3.0) < C_2H_5(4.0) = C_3H_7(4.0) <$ iso-$C_3H_7(7.5)$. The rate constants ($k \cdot 10^4$ sec^{-1}) are given in brackets.

We should note, however, that the peculiarities of hydrogen exchange in anisole with solutions of potassamide in liquid ammonia, cannot all be explained by the inductive effect of the hydrogen atom of the methoxyl group. For example, it is not clear why the H atoms of the ring exchange more rapidly than the H atoms of the methoxyl group in this case. Since the inductive effect is rapidly attenuated along a chain of carbon atoms, then the H atoms in the methoxyl group should exchange more rapidly than the meta atoms and much more rapidly than the para-H atoms. Evidently, the mutual effect of the atoms in the anisole molecule has its peculiarities, which require further study and cannot be interpreted from the generally accepted point of view at the moment.

Hydrogen exchange in diphenyl ether. $(C_6H_5)_2O$ is readily soluble in ND_3. In the presence of KND_2, the solutions acquired a yellow color. The substance was isolated after the experiment, as with anisole, and distilled in vacuum over sodium. The constants were unchanged after the experiment. The results of the exchange experiments are shown by the data in Table 5.

After only 15 minutes, the hydrogen exchange was close to complete. Under the same conditions, benzene

*We should note that in his work [7] Roberts mentioned neither this fact nor all the work on hydrogen exchange in liquid ammonia, performed in the Isotope Reaction Laboratory of the Karpov Institute from 1947 onward. Roberts implied that the study of hydrogen exchange in solutions of potassamide in liquid ammonia originated in the USA in 1954.

TABLE 5

Hydrogen Exchange in Diphenyl Ether (25°)

Expt. No.	T	c_{KND_2}	$\frac{m_s}{m_w}$	$\frac{m_{KND_2}}{m_w}$	c_s^0	c_w	n
1	15 min	0.028	62	0.05	4.38	3.07	8.1
2	15 »	0.046	190	0.25	5.34	4.42	9.1
3	20 »	0.049	63	0.09	5.36	4.03	8.7
4	1 hours	0.028	70	0.06	4.38	3.50	9.2
5	1 »	0.046	83	0.11	5.34	4.86	10.2

exchanged less than a third of its H atoms (1.8 out of 6), anisole exchanged only the two most labile ortho-H atoms in the ring and diphenyl [12] exchanged about 2 H atoms. Consequently, the exchange of hydrogen in diphenyl ether proceeds much more rapidly than that in benzene, anisole and diphenyl. If hydrogen exchange in $(C_6H_5)_2O$ with ammoniacal alkali, as in the case of exchange with acid DBr [1], depended on p,π-conjugation, then one would expect the hydrogen exchange to be slower than in benzene. Actually, the exchange occurs more rapidly, regardless of whether an acid or a base participates in the reaction.

Diphenyl ether differs from anisole in that the position of the methyl group, which lacks π-electrons, is occupied by a phenyl group. The $(C_6H_5)_2O$ molecule has a polarizability ($20.8 \cdot 10^{-24}$ cm^3) greater than the anisole molecule ($13.1 \cdot 10^{-24}$ cm^3). Apparently, this plays a determining role in hydrogen exchange with a base.

DISCUSSION OF RESULTS

Data obtained by studying hydrogen exchange in oxygen- and nitrogen-containing aromatic compounds with acidic [1] and basic solvents, leads to certain conclusions on the mechanism of hydrogen exchange. In 1934, Ingold et al. [6] showed that deuterium exchange in the acid medium proceeded by a type of electrophilic substitution. This hypothesis was confirmed on many examples in our laboratory [8], in particular, in the previous paper [1]. In this it was very clearly shown that,if, due to satiation of the free electron pair of the nitrogen atom, the degree of electronegativity of the carbon atoms of the aromatic amine is lowered, and therefore the addition to them of deuterons of the acid becomes less probable, then the exchange reaction is inhibited. This is conclusive evidence that the necessary condition for the exchange reaction with an acid is just this addition of D to the carbon atom of the C−H bond.

On the other hand, for an exchange reaction to occur with a base participating, the latter must protonize the hydrogen of the C−H bond. Here, the free carbanions do not have to form (the same as in the case of free carbonium ions in the reaction with an acid). The fact that in hydrogen exchange catalyzed by a base, the substance is a proton donor is also indicated by the deep analogy between the metallation of aromatic substances by alkaliorganic compounds and hydrogen exchange in a basic medium, as has been noted several times in work from our laboratory [9]. The mechanism of metallation by alkaliorganic compounds has been explained by many papers [16]. From Bryce-Smith's proposal, this mechanism has been given the designation "protophilic." The attack of a nucleophilic reagent is directed not toward the carbon atom of the C−H bond (as occurs in the nucleophilic substitution of H), but toward the H atom. The metal cation is added to the negatively charged carbon atom only in the second stage. The exchange of hydrogen catalyzed by ND_2^- ion proceeds similarly. The ND_2^- ion attracts the hydrogen of the C−H bond in the form of a proton and this allows the D of ND_3 to add to the carbon atom. This process may occur in a single act in an activated complex. Therefore, the similarity between the laws of metallation and hydrogen exchange in ammoniacal alkali for anisole are understandable. In the opinion of Roberts [7], the primary attack of the ND_2^- ion does not involve the π-electron system of the ring, as occurs in nucleophilic aromatic substitution.

The hypothesis on the mechanism of exchange reactions presented is supported by ideas [9, 17] on the effect of the charge of the substance on the rate of hydrogen exchange, which have received further confirmation in this work.

We plan to supplement our investigations with data on hydrogen exchange in aromatic amines with solutions of potassamide in liquid ammonia and on deuterium exchange with DF and DF + BF_3 in aromatic compounds with substituents containing oxygen and nitrogen and also to measure the rate of deuterium exchange of the nonequivalent hydrogen atoms in diphenyl ether.

SUMMARY

1. All the hydrogen atoms in the phenolate ion, diphenyl ether and anisole, exchange with a solution of KND_2 in liquid ND_3. Since the amide ion is a very strong base, the differences in acidity and reactivity in exchange of the nonequivalent hydrogen atoms of the aromatic rings in the substances named were considerably leveled out.

2. Hydrogen in the phenolate ion exchanges at a rate three orders less than in benzene. This is explained by the fact that the negative charge of the ND_2^- ion hinders the approach of the catalyst.

3. The hydrogen in diphenyl ether exchanges considerably more quickly than that in benzene.

4. The rate of hydrogen exchange in anisole falls in the sequence: ortho > meta > para > OCH_3. This order indicates that in contrast to the exchange with an acid, in the exchange of hydrogen in the ring with a base, the main role is played not by the π,p-conjugation effect, but by the inductive effect of the methoxyl group oxygen. The hydrogen of the latter exchanges more slowly than the para atom of the anisole-aromatic ring.

5. Considerations on the mechanism of hydrogen exchange with acids and bases are discussed.

6. Methods are presented for preparing the deuteroanisoles: $C_6D_5OCD_3$, $C_6H_5OCD_3$, 2,4,6-$C_6D_3H_2OCH_3$, 3,5-$C_6D_2H_3OCH_3$ and p-$C_6DH_4OCH_3$, using exchange reactions in various solvents.

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ISOTOPE EXCHANGE OF 2-MERCAPTOBENZTHIAZOLE SULFUR AND ELEMENTARY SULFUR IN THE PRESENCE OF AMINES

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In investigations published previously [1-3], it was shown that vulcanization accelerators react with sulfur during rubber vulcanization. It was established experimentally, using radioactive isotopes, that there is a rapid isotope exchange of sulfur atoms between the accelerators and the materials being vulcanized, during rubber vulcanization. It was found that the more efficient the accelerator, the lower the temperature at which the isotope exchange of sulfur atoms occurred and the greater the rate [4].

It is known that amines were the first organic accelerators used in the rubber industry [5] and that they are still important in the technology of rubber preparation. The addition of amines to the rubber raises the activity and efficiency of the sulfur-containing, organic rubber vulcanization accelerators.

Elucidation of the effect of amines on the rate of isotope exchange of sulfur atoms of the most widely used accelerator, 2-mercaptobenzthiazole (Captax), and the vulcanization agent, elementary sulfur, is of both practical and theoretical value. If the hypothesis on the correlation between vulcanization rate and isotope-exchange rate is correct, then a more rapid sulfur exchange may be expected in the presence of amines.

EXPERIMENTAL

A study was made of the effect of tertiary (triethylamine) and secondary (dipropylamine and diamylamine) amines on the exchange of sulfur atoms between 2-mercaptobenzthiazole and elementary sulfur over a wide temperature range.

2-Mercaptobenzthiazole and radioactive sulfur (S^{35}) were used in equimolecular amounts. The amines were introduced into the reaction medium in amounts of 0.1 to 1.0 parts relative to the amount of accelerator.

The experiments were performed in sealed ampoules in naphthalene solution, in approximation of the rubber system. Into the ampoules was placed 0.08 g of 2-mercaptobenzthiazole and 0.0153 g of radioactive sulfur, dissolved in 2.29 g of naphthalene. The amines were added before the ampoules were sealed. The sealed ampoules were kept for five minutes on a water bath to dissolve the accelerator and the sulfur in the naphthalene completely, and then heated in a thermostat under strictly defined temperature conditions. After being heated, the ampoules were opened, 5 ml of toluene added to the contents, and the ampoules placed in a beaker with boiling water until the whole mass dissolved. The solution was then poured into a separating funnel in which was placed 10 ml of 1% sodium hydroxide solution. The mercaptobenzthiazole passed into the aqueous layer as the sodium salt and the radioactive sulfur remained in the layer of organic solvent. The mercaptobenzthiazole and sulfur were thus separated.

The addition of hydrochloric acid to the alkaline solution liberated the mercaptobenzthiazole, which was recrystallized several times until its melting point reached 176-178°. The mercaptobenzthiazole, isolated after the exchange reaction, was examined for radioactivity by the procedure described previously [6], using an end-window counter for soft β-radiation. The percentage of sulfur-isotope exchange was calculated on the basis of the fact we demonstrated experimentally, that only the sulfur of the mercaptobenzthiazole sulfhydryl group participates in the isotope exchange [7].

We studied the isotope exchange of sulfur atoms at temperatures of 100, 120 and 140°, i.e., at temperatures at which rubber mixtures and their vulcanizates are prepared.

Isotope Exchange of 2-Mercaptobenzthiazole Sulfur and Elementary Sulfur in the Presence of Amines

Experimental conditions		Initial radioactivity of sulfur (counts/mg per 5 min) (S*)	Theoretical number of counts at complete exchange per mg of sulfur	Exptl. No. of counts per mg of sulfur in mercaptobenzthiazole	Percent exchange			
time (in min)	temperature				without amines	dipropylamine	diamylamine	triethylamine
90	100°	9949	4975	98	1.9	—	—	—
				490	—	9.8	—	—
				355	—	—	7.1	—
				855	—	—	—	17.4
240	100	10160	5080	324	6.3	—	—	—
				897	—	17.6	—	—
				621	—	—	12.2	—
				1107	—	—	—	21.8
360	100	998	499	105	21	—	—	—
				242	—	48	—	—
				252	—	—	—	50.6
60	120	1035	517	137	26	—	—	—
				203	—	39	—	—
				203	—	—	39	—
				208	—	—	—	40.5
120	120	1367	683	279	41	—	—	—
		9631	4810	2442	—	—	50.7	—
				2645	—	—	—	54.9
240	120	1411	705	437	62	—	—	—
		9419	4710	4679	—	99.3	—	—
		9737	4869	3816	—	—	78.3	—
				3857	—	—	—	79.2
360	120	9313	4656	3837	82	100	100	100
30	140	1173	587	363	62	—	—	—
				555	—	95	—	—
				563	—	—	96	—
60	140	1352	676	476	70	100	100	100
90	140	1061	530	742	100	100	100	100

Analysis of the experimental data given in the Table showed that the exchange of sulfur atoms increased sharply in the presence of minute quantities of amines. It is interesting to note the fact that the strongest acceleration of the isotope exchange of sulfur atoms in the presence of amines was observed at 100°, i.e., at the temperature at which rubber is mixed with the ingredients and there is the greatest danger of premature scorching in the rubber mixtures. It is well known in technological practice that cases of premature scorching of rubber mixtures during their preparation or storage are most common in the presence of sulfur-containing accelerators and amine activators. Acceleration of isotope exchange was also observed at 120 and 140°, i.e., at conditions of technical vulcanization; in the presence of amine at 140°, complete exchange was achieved in approximately 30 minutes, while without amines it occurred only after 90 minutes.

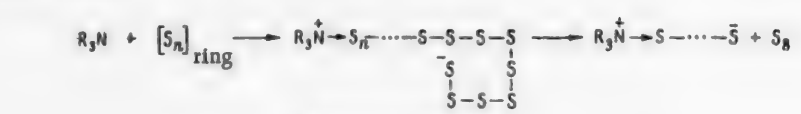
The experimental data obtained do not, however, allow us to differentiate between the effect on the isotope-exchange rate of the secondary and tertiary amines investigated. The data obtained agree well with those in [8], which demonstrated that the isotope exchange of 2-mercaptobenzthiazole sulfur with elementary sulfur was accelerated by the presence of a sulfur-free nitrogen-containing accelerator – diphenylguanidine (DPG). It is known that the use of the combination of accelerators, mercaptobenzthiazole–diphenylguanidine, has a greater accelerating effect than the action of each accelerator separately.

Thus one may conclude that amines, which accelerate the action of sulfur-containing accelerators, also accelerate isotope exchange of sulfur atoms of the accelerators and the vulcanizing agents.

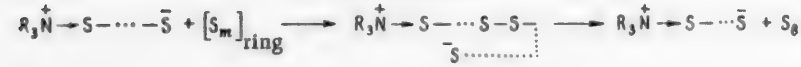
How can one explain the acceleration of isotope exchange of sulfur atoms in the presence of amines? It is known that amines have a catalytic effect on the allotropic changes of sulfur [9]. There is reason to believe that the insoluble modifications of sulfur consist of high-molecular rings and not of chains [10]. This ring must be broken at some place to convert the insoluble to a soluble sulfur modification. The energy of the simple

S–S bond in the ring was evaluated as 63.8 kcal per mole, i.e., very great. The sulfur rings may be broken either thermally or catalytically. The basic amines are an active group of catalysts, which convert high-molecular sulfur atom rings to eight-membered rings. It is known that the insoluble form of sulfur dissolves almost instantaneously in benzene or carbon disulfide if it is shaken with a drop of amine [11] to form the intermediate aminopolysulfide. According to Krebs [9], the rate at which insoluble sulfur converts to soluble sulfur may best be explained on the basis of chain-reaction principles.

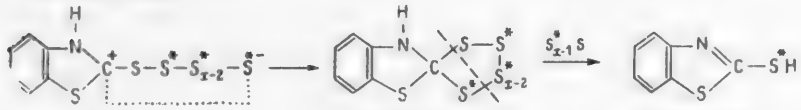
Both ends of the broken sulfur ring are extremely reactive and may behave ionogenically. Under the effect of the aminopolysulfide formed, the chain reaction continues until the ends of the same sulfur ring react with each other to form a ring or with another component (in our case, with the accelerator). The activation of sulfur by the action of amines to form aminopolysulfides and eight-membered sulfur rings may be represented by the following scheme:



Aminopolysulfide



2-mercaptobenzthiazole
(thione form)



Intermediate radioactive polysulfide of the accelerator

Radioactive accelerator

On reacting with the active forms of the accelerator, the aminopolysulfides decompose to form an unstable intermediate polysulfide compound of the accelerator. The decomposition of the polysulfide accelerator formed results in the exchange of sulfur atoms and the liberation of active sulfur, which reacts chemically with the molecular structure of the rubber.

It should also be noted that the accelerating action of sulfur-free, amino-containing accelerators of rubber vulcanization is based on the formation of aminopolysulfides and their decomposition with the liberation of active sulfur. On the other hand, reaction with the basic amines converts mercaptobenzthiazole to an ionic form, which reacts with aminopolysulfide to form an intermediate polysulfide complex, also, and during its decomposition isotope exchange of sulfur atoms occurs.

Thus, under the action of amines, the bonds between the atoms in sulfur rings are broken heterolytically and this accelerates the formation of an intermediate polysulfide compound of the accelerator, which decomposes with exchange of sulfur atoms.

We are grateful to E.N. Gur'ianova for her help in carrying out this investigation.

SUMMARY

1. A study was made of the kinetics of the exchange between 2-mercaptobenzthiazole sulfur and elementary sulfur in the presence of the amines, dipropylamine, diamylamine and triethylamine at 100, 120 and 140°.

2. It was shown that amines accelerate isotope exchange of the sulfur atoms of the rubber-vulcanization

accelerator, 2-mercaptobenzthiazole (Captax), and elementary sulfur, which agrees well with the technological practice of efficient rubber vulcanization in the presence of amines.

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DEHYDROGENATION KINETICS OF CYCLOHEXANE AND ITS HOMOLOGS ON A CHROMIUM CATALYST AT ATMOSPHERIC PRESSURE

G.N. Maslianskii and N.R. Bursian

The dehydrogenation of six-membered naphthenes on oxide catalysts at atmospheric pressure has been studied by many authors and a large amount of experimental material has been accumulated in this field [1]. The reaction kinetics of cyclohexane dehydrogenation on a chromium catalyst were first studied by A.A. Balandin and N.N. Brusov [2] and also by B.L. Moldavskii, et al. [3]. Later, the dehydrogenation of six-membered naphthenes on chromium catalysts was studied in other works by A.A. Balandin, et al. [4-6]. The kinetics of the same reaction were also studied by other authors [7-10]. Despite this, some data on the kinetics of cyclohexane dehydrogenation are contradictory. Thus, the investigations of M.Ia. Kagan, et al. [7-9], show that the rate of the dehydrogenation reaction is inversely proportional to the concentration of hydrogen in the gas phase. Starting from this, a kinetic equation was set up, allowing for inhibition of the reaction by hydrogen.

On the other hand, E.F. Herrington and E.K. Rideal [10] came to the conclusion that in the dehydrogenation of cyclohexane on a Cr_2O_3/Al_2O_3 catalyst, the benzene and hydrogen acted as diluents and had no inhibiting action on the reaction. Thus, while the data of the authors mentioned on the effect of benzene on the reaction kinetics of cyclohexane dehydrogenation agree, the data with regard to hydrogen are contradictory.

According to the data of different authors, the value of the apparent activation energy of cyclohexane dehydrogenation on different chromium catalysts varies over the range of 26,000-40,700 cal/mole [2, 3, 8, 10].

In the present work* a study was made of the dehydrogenation kinetics of cyclohexane on an alumino-chromium catalyst (Cr_2O_3/Al_2O_3) at atmospheric pressure. In addition, measurements were made on the relative dehydrogenation rates of some cyclohexane homologs (methylcyclohexane, 1,3-dimethylcyclohexane, 1,3,5-trimethylcyclohexane and isopropylcyclohexane).

Further investigations, devoted to studying the reaction kinetics of cyclohexane dehydrogenation on oxide catalysts at elevated pressures, will be reported in later communications.

EXPERIMENTAL

Procedure and Starting Materials

Cyclohexane and its homologs were prepared by hydrogenating the appropriate aromatic hydrocarbons over a nickel catalyst. The characteristics of the hydrocarbons used in the work are given in Table 1.

The experiments were performed in a flow apparatus.

The reactor was a glass tube placed vertically in an electric furnace. The catalyst (20 ml) was placed in a constant temperature zone. During the experiments the temperature was maintained with an accuracy of $\pm 1^\circ$.

The hydrocarbon was fed steadily into the reactor from a graduated burette. The reaction products emerging from the reactor were passed into a condenser. The condensed hydrocarbons were collected in a receiver. The gaseous reaction products were collected in graduated burettes.

*Dissertation work of N.R. Bursian, completed in 1947.

TABLE 1

Name of hydrocarbon	Present work			Literature data [11]		
	boiling point (760 mm)	n_4^{20}	d_4^{20}	boiling point (760 mm)	n_D^{20}	d_4^{20}
Cyclohexane	80.8°	1.4262	0.7781	80.75°	1.4262	0.7786
Methylcyclohexane	100.8	1.4232	0.7694	100.93	1.4231	0.7694
Ethylcyclohexane	131.3	1.4332	0.7884	131.78	1.4330	0.7879
Dimethylcyclohexane (mixture of isomers)	120—124	1.425₂	0.7701	—	—	—
1,3,5-Trimethylcyclohexane	138—139.5	1.4283	0.7761	140.4—140.9*	1.4277 *	0.7765 *
				138—139**	1.4251 **	0.7720 **
Isopropylcyclohexane	152—155	1.4400	0.7983	154.56	1.4409	0.8022

*Cis-isomer.

**Trans-isomer.

The duration of an experiment was usually two to three hours. Every five minutes readings were taken of the amount of hydrocarbon introduced, the temperature and the amount of gas liberated. The rate of hydrogen liberation and the agreement of the refractive indexes of catalyzate samples indicated the constancy of the catalyst activity with time. In addition, control experiments with cyclohexane were performed periodically during the course of the whole series of experiments. If a fall in the catalyst's activity was observed, then it was regenerated with air. The regeneration conditions were chosen on the basis of special work and gave good reproducibility of catalyst activity [12].

It was established that in the dehydrogenation of cyclohexane, the catalyzates obtained contained insignificant amounts of unsaturated hydrocarbons; therefore, it was possible to determine the benzene content from the refractive index [13] on the one hand, and from the amount of hydrogen liberated on the other.

In contrast to the dehydrogenation products of cyclohexane, the catalyzates obtained by dehydrogenating its homologs contained noticeable amounts of unsaturated hydrocarbons. Due to this, the amount of aromatic hydrocarbons was determined by a dispersion method [14]. The appropriate measurements were performed on a Pulfrich refractometer. The content of unsaturateds was calculated from the bromine number, which was determined by the method of Francis [15].

The catalyst was prepared by coprecipitation of chromium and aluminum hydroxides. The prepared, baked catalyst contained 20% of Cr_2O_3 and 80% of Al_2O_3.

Kinetics of Cyclohexane Dehydrogenation on a Chromium Catalyst

The dehydrogenation kinetics of cyclohexane were studied at 410-475°.

We used the equation developed by A.V. Frost [16] to describe the kinetics of the reaction studied.

If we consider that the catalyst surface is uniform and that the adsorption of the starting material and the reaction products is governed by the Langmuir equation, then the reaction rate, expressed as the number of moles reacting in unit time on unit surface, will equal:

$$\frac{\partial^2 x}{\partial t \partial S} = \frac{k_1 b_1 P_1}{1 + b_1 P_1 + b_2 P_2 + \ldots \ldots b_i P_i}, \qquad (1)$$

where k_1 is the rate constant of the surface reaction, relative to 1 cm² in unit time, b_1, b_2 and b_i are the adsorption coefficients of the substances and P_1, P_2 and P_i are the partial pressures corresponding to these substances at a moment of time when the degree of conversion has reached a value y.

Transposition and integration of this equation gives the following expression for the rate constant of a monomolecular, heterogeneous, catalytic reaction, occurring in a flow system and inhibited by the reaction products:

TABLE 2

The Effect of the Rate of Input of Cyclohexane on Its Degree of Dehydrogenation (Chromium catalyst – sample 1, 450°)

Expt. No.	Cyclohexane input		Amt. of gas (in ml) liberated in 5 min	n_D^{20} of catalyzate	Percent of dehydrogenation			$\alpha \cdot 10^3$ (mole per min)
	ml/hr	m mole/per min			from gas	from n_D^{20}	average	
1	60.0	9.2	416	1.4335	13.4	13.8	13.6	0.26
2 *	29.6	4.56	302	1.4375	19.7	20.5	20.1	0.24
3	15.0	2.31	231	1.4445	29.7	32.3	31.0	0.24
4 *	30.0	4.62	309	1.4365	19.9	18.8	19.3	0.22
5	5.5	0.85	140	1.4595	48.8	54.0	51.4	0.25
6 *	30.0	4.62	298	1.4365	19.2	18.8	19.0	0.22
7	3.0	0.46	106	1.4700	68.0	67.5	67.8	0.25
8 *	30.0	4.62	323	1.4380	20.8	21.3	21.0	0.25

*Control experiments.

TABLE 3

The Effect of Reaction Temperature on the Rate of Cyclohexane Dehydrogenation (Chromium catalyst – sample 1)

Exptl. conditions			Amt. of gas (in ml) liberated in 5 min	n_D^{20} of catalyzate	Percent of dehydrogenation			$\alpha \cdot 10^3$ (mole per min)
temperature	cyclohexane input				from gas	from n_D^{20}	average	
	ml/hr	m mole/per min						
450°	30.0	4.62	323	1.4380	20.8	21.3	21.0	0.25
410	7.2	1.11	65	1.4370	17.4	19.8	18.6	0.05
430	15.0	2.31	152	1.4370	19.4	19.8	19.6	0.11
450	30.0	4.62	320	1.4380	20.6	21.3	20.9	0.25
475	60.0	9.2	490	1.4404	26.2	25.8	26.0	0.7
450	30.0	4.62	309	1.4365	19.9	18.8	19.3	0.22

$$\alpha = v_0 \ln \frac{1}{1-y} - \beta v_0 y, \qquad (2)$$

where α is a value proportional to the reaction rate constant, v_0 is the number of moles of starting material introduced per minute, y is the degree of conversion of the starting material, and β is a value, characterizing the constancy of the ratio of the adsorption coefficients.

At constant temperatures and pressures, the values α and β do not depend on v_0 and y; consequently, Equation (2) gives a straight line in the coordinates $v_0 y$ and $v_0 \ln \frac{1}{1-y}$.

To elucidate the effect of the volume rate on the course of the reaction, a series of experiments was performed at 450°. The cyclohexane input was varied over the wide limits from 3 to 60 ml per hour, i.e., by a factor of 20; the degree of conversion changed from 13.6 to 67.8%, respectively. The experimental results are given in Table 2. The constancy of the catalyst's activity was confirmed quite satisfactorily by the reproducibility of control experiments.

The values of $v_0 \ln \frac{1}{1-y}$ and $v_0 y$, calculated from Equation (2) for the experiments in Table 2, lie well

on a straight line. Calculating by the method of least squares, it was found that $\alpha = 0.24 \cdot 10^{-3}$, $\beta = 0.86$.

The deviations of the values calculated for separate experiments from the value given above, did not exceed the limits of error of the experiment.

To establish the dependence of reaction rate on temperature, a series of experiments was performed at 410-475° and the results are given in Table 3. A plot of $\log \alpha$ against 1/T gave a straight line, which was described by the equation:

$$\log \alpha = 8.8 - \frac{8960}{T}. \quad (3)$$

The value of the apparent activation energy, calculated from Equation (3) was 41,000 cal/mole.

The applicability of Equation (2) to the reaction studied indicates that the reaction rate increases as the partial pressure of cyclohexane increases and that it is inhibited by the reaction products.

To elucidate the effect of benzene on the course of the reaction, a series of experiments was carried out with mixtures of benzene and cyclohexane in equal amounts at 450°. The results of the experiments are given in Table 4.

TABLE 4

Experiments on the Dehydrogenation of Cyclohexane Mixed With Benzene (Chromium catalyst – sample 1, 450°)

Exptl. conditions			Amt. of gas (in ml) liberated in 5 minutes	n_D^{20} of catalyzate	Percent of cyclohexane dehydrogenated		
comp. starting mixture (in mole %)		mixture input (mmole per min)			from gas	from n_D^{20}	average
C_6H_{12}	C_6H_6						
100	—	4.62	319	1.4380	20.5	21.3	20.9
89.3	10.7	4.69	305	1.4430	21.6	21.6	21.6
80.2	19.8	4.82	254	1.4470	19.6	20.6	20.1
67.7	32.3	4.88	239	1.4532	21.6	19.5	20.5
40.2	59.8	5.14	147	1.4696	21.2	18.2	19.7
100	—	4.62	319	1.4380	20.5	21.3	20.9

On changing the molar concentration of benzene in the mixture from 10.7 to 59.8%, the degree of conversion of cyclohexane remained practically constant. Consequently, benzene does not slow down the dehydrogenation of cyclohexane on a chromium catalyst and is only a diluent.

The problem of the effect of hydrogen on the reaction kinetics of cyclohexane dehydrogenation were studied in an investigation of this reaction under a pressure of hydrogen.* It was established that the reaction was inhibited by hydrogen.

Thus, our data agree with the data of M.Ia. Kagan [7] and contradict the results obtained by Herrington and Rideal [10].

A Study of the Relative Dehydrogenation Rates of Six-Membered Naphthenes on a Chromium Catalyst

For studying the relative dehydrogenation rates, we chose six-membered naphthene hydrocarbons, which differed both in the number and the character of the substituent groups on the hexamethylene ring. We used the following hydrocarbons: cyclohexane, methylcyclohexane, dimethylcyclohexane (a mixture of isomers), 1,3,5-trimethylcyclohexane, ethylcyclohexane and isopropylcyclohexane.

*The results of the investigation will be put into the next communication.

TABLE 5

Experiments on the Dehydrogenation of Different Six-Membered Naphthenes (Chromium catalyst – sample 2, 450°)

Hydrocarbon input		Catalyzate characteristics		Catalyzate composition (wt. %)		Degree of conversion (100 y) (in mole %)	$\alpha \cdot 10^3$ (mole/min)
ml/hr	m mole/per min	bromine number	δ_{Fe}^{*}	unsaturateds	aromatics		
Cyclohexane							
29.6	4.57	6.3	106.5	3.2	11.4	15.5	0.25
14.2	2.18	7.5	112.7	3.8	18.2	23.0	0.25
5.5	0.93	7.5	123.1	3.8	20.5	34.8	0.25
Methylcyclohexane							
29.2	3.82	5.0	112.3	3.0	16.6	20.2	0.36
15.0	1.96	4.0	119.3	2.4	25.0	28.6	0.36
5.0	0.66	5.3	133.0	3.2	40.9	45.6	0.33
Dimethylcyclohexane (mixture of isomers)							
31.0	3.58	4.3	114.2	3.0	18.5	22.4	0.42
14.4	1.65	4.5	124.9	3.1	32.0	36.3	0.47
5.8	0.66	4.3	136.2	3.0	46.1	50.5	0.42
Ethylcyclohexane							
29.5	3.46	5.3	115.2	3.6	21.2	25.8	0.50
14.4	1.69	5.5	122.9	3.8	30.8	35.7	0.47
6.5	0.76	5.5	133.7	3.8	44.1	49.3	0.44
Isopropylcyclohexane							
30.0	3.16	3.2	116.3	2.5	25.2	28.7	0.55
15.6	1.65	4.7	121.9	3.6	32.0	36.8	0.50
7.0	0.74	5.5	135.2	4.3	48.4	53.8	0.53
1,3,5-Trimethylcyclohexane							
30.0	3.08	3.9	119.1	3.0	23.9	27.8	0.53
21.6	2.22	4.5	123.4	3.5	29.2	33.6	0.55
14.6	1.50	4.1	128.8	3.2	36.2	40.5	0.53

*Specific dispersion at 20°.

For each naphthene hydrocarbon we performed a series of three experiments, which differed in the input-volume rate of the hydrocarbon. To check the stability of the catalyst, each series of experiments was begun and ended with a control experiment with cyclohexane.

The results of the experiments with different six-membered naphthenes are given in Table 5.

The catalyzates obtained by dehydrogenating the naphthenes studied contained unsaturated hydrocarbons together with the aromatics. The amount of the former, however, was small and varied over the range of 2 to 4% by weight.

The degree of conversion presented in Table 5 (y) was calculated in the following way: the aromatic and unsaturated hydrocarbon contents of the catalyzates were expressed in molar percents and then the values obtained were added.

The reaction-rate constants were calculated by Equation (2), as in experiments with cyclohexane. The constant α was found to be quite invariant in each of the series of experiments with the hydrocarbons studied.

The average values of the reaction-rate constants ($\alpha \cdot 10^3$) for the dehydrogenation of six-membered naphthenes at 450° on a chromium catalyst, from the data in Table 5, are given below.

Cyclohexane	0.25	Ethylcyclohexane	0.47
Methylcyclohexane	0.35	1,3,5-Trimethylcyclohexane	0.54
Dimethylcyclohexane	0.44	Isopropylcyclohexane	0.53

If we consider that the rate of cyclohexane dehydrogenation equals unity, then the relative rates of dehydrogenation of its homologs equal:

Cyclohexane	1	Ethylcyclohexane	1.9
Methylcyclohexane	1.4	1,3,5-Trimethylcyclohexane	2.2
Dimethylcyclohexane (mixture of isomers)	1.8	Isopropylcyclohexane	2.1

Thus, one can conclude that with an increase in the molecular weight of six-membered naphthene hydrocarbons, the rate of their dehydrogenation on a chromium catalyst increases regularly.

SUMMARY

1. A study was made of the reaction kinetics of cyclohexane dehydrogenation on a chromium catalyst at 410-475° and atmospheric pressure.

2. It was established that the rate of the dehydrogenation reaction was described by the kinetic equation for a monomolecular reaction,and inhibited by the products of the latter.

3. It was shown that benzene did not slow down the reaction.

4. It was found that the rate of dehydrogenation of six-membered naphthenes increased regularly with an increase in the hydrocarbon's molecular weight.

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A STUDY OF THE DEHYDROGENATION OF CYCLOHEXANE ON A CHROMIUM CATALYST UNDER A PRESSURE OF HYDROGEN

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The success of the industrial application of the catalytic aromatization of hydrocarbons over the last twenty years is closely connected with the realization of this process at an elevated pressure and in the presence of hydrogen [1, 2]. Despite this, very few works [3-5] have been devoted to studying the aromatization of individual hydrocarbons on oxide catalysts at elevated pressures. The kinetics of dehydrogenation of six-membered naphthenes on these catalysts under a pressure of hydrogen, in general, has been studied little.

The aim of the present work was to study the kinetic laws of cyclohexane dehydrogenation on a (Cr_2O_3/Al_2O_3) chromium catalyst at an elevated pressure.*

It was established that the reaction rate was proportional to the partial pressure of cyclohexane in the range from 0.5 to 4.0 atm.

On the other hand, increasing the partial pressure of hydrogen caused a sharp fall in the rate of cyclohexane dehydrogenation. Since the effect of hydrogen pressure was studied under conditions at which the concentrations of the reacting materials were far from equilibrium, one may conclude that the reason for the inhibition of the reaction by hydrogen is connected with the kinetics of the reaction studied. The facts established allow the reaction rate of cyclohexane dehydrogenation at elevated pressures to be expressed by a kinetic equation, allowing for inhibition of the reaction by hydrogen.

The investigations showed that the kinetics rules, established for the dehydrogenation of cyclohexane on a chromium catalyst at atmospheric pressure [6], remain accurate when the reaction is performed at pressures of up to 20 atm.

It is noteworthy that despite the fact that the chromium catalyst used showed a high activity in operation at atmospheric pressure [6], the degree of cyclohexane conversion in experiments with a pressure of hydrogen was small, although the reaction temperature exceeded 500°. Greensfelder, et al., [5] also observed a sharp fall in hydrocarbon aromatization when the same reaction was performed over a chromium catalyst under a pressure of hydrogen.

Analysis of the results obtained showed that the low degree of cyclohexane conversion in experiments under pressure cannot be ascribed to inhibition of the reaction by hydrogen alone, but is also connected with deactivation of the catalyst during its preliminary treatment with hydrogen, which was performed at 550° and a pressure of 20 atm [7].

Thus, in an experiment at atmospheric pressure and 475° with a cyclohexane input of 0.46 mole/min per liter of catalyst, 26% of the cyclohexane reacted [6]. On the other hand, calculation** showed that under the same conditions, not more than 2% of the cyclohexane should be converted on the portion of catalyst used in experiments under pressure. Thus, portions of the same sample of catalyst, used in experiments at atmospheric and elevated pressures, differed sharply in activity.

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*Dissertation work of N.R. Bursian, completed in 1947.

**The calculation was carried out using formula (3) (see next page) and the experimentally found value of the apparent activation energy of cyclohexane dehydrogenation. It was assumed that P = 1 atm and $\alpha = 0$.

A similar deactivation is apparently one of the reasons for the extremely limited use of chromium catalyst in present-day aromatization processes [2], which, as mentioned above, are performed under a pressure of hydrogen.

EXPERIMENTAL

Procedures and Starting Materials

The experiments were performed in a flow-type apparatus, which could operate at high temperatures and pressures [9]. The catalyst was prepared by coprecipitation of chromium and aluminum hydroxides. The prepared, baked catalyst contained 20% Cr_2O_3 and 80% Al_2O_3. The cyclohexane was prepared by hydrogenation of benzene over a nickel catalyst.

B.p. 80.8° (760 mm), d_4^{20} 0.7781, n_D^{20} 1.4262. Literature data [8]: b.p. 80.75°(760 mm), d_4^{20} 0.7786, n_D^{20} 1.4262.

The stability of the catalyst was tested by means of control experiments. When a fall in the activity of the catalyst was observed, the catalyst was regenerated. The regeneration was realized by passing air through the catalyst at 550°.

After regeneration, the catalyst was reduced with hydrogen at 550° and 20 atm pressure. The volume rate of hydrogen input was 1000.

Catalyzates obtained in experiments under pressure contained some unsaturateds. Due to this, the amount of aromatic hydrocarbons was determined by a dispersion method [10]. The appropriate measurements were performed on a Pulfrich refractometer. The unsaturated hydrocarbon content was calculated from the bromine numbers [11].

Derivation of Kinetic Equation

The kinetics of cyclohexane dehydrogenation on a chromium catalyst were studied over the range 505-550° and at partial hydrogen pressures not exceeding 20 atm. As was shown by V.R. Zharkova and A.V. Frost [12], under these conditions the equilibrium of this reaction is completely displaced toward benzene.

Analysis of the experimental data showed that the reaction rate may be expressed by an equation, allowing for inhibition of the reaction by hydrogen

$$w = \frac{k \cdot P_{C_6H_{12}}}{1 + bP_{H_2}}, \tag{1}$$

where w is the reaction rate expressed in the number of moles reacting in one minute on unit catalyst surface, k is the reaction constant, $P_{C_6H_{12}}$ and P_{H_2} are the partial pressures of cyclohexane and hydrogen and b is a coefficient equal to 0.2.

The equation was transposed and integrated as A.V. Frost [13] did for the kinetic equation he deduced.

Substituting the values of $P_{C_6H_{12}}$ and P_{H_2} in Equation (1), we obtain

$$w = \frac{k(1-y)P}{1 + \alpha(1+bP) + 3(1+bP)y}, \tag{2}$$

where P is the total pressure in the reactor; y is the degree of cyclohexane conversion and α is the molar ratio of hydrogen: cyclohexane.

As a result of integrating, we find:

$$S \cdot k = k' = v_0 \frac{1+bP}{P}\left[\left(\frac{1}{1+bP} + \alpha + 3\right)\ln\frac{1}{1-y} - 3y\right], \tag{3}$$

where S is the total surface of the catalyst in the reactor.

In determining the degree of conversion y, the portions of cyclohexane converted into benzene and unsaturated hydrocarbon were added together.

We should note that despite the fact that the experiments under pressure were performed at high temperatures, the catalyzates contained practically only cyclohexane besides the aromatic and unsaturated hydrocarbons. Thus, when the catalyzates were treated with 98% sulfuric acid, the physical constants of the unreacted part of the catalyzate agreed with those of the starting cyclohexane.

TABLE 1

Effect of Volume Rate and Temperature on the Dehydrogenation of Cyclohexane (Chromium catalyst – sample 1)

Exptl. conditions				Analysis results (in wt. %)		Cyclohexane reacted (mole %)	$k' \cdot 10^3$
temperature	operating pressure (atm)	C_6H_{12} input (mmoles per min)	molar ratio of H_2:C_6H_{12}	unsaturateds	aromatics		
550°	6	24.64	4.5	5.5	6.3	12.2	6.0
550	6	12.32	4.2	6.5	15.2	22.7	5.8
550	6	6.16	3.4	6.9	33.8	42.3	5.7
505	6	12.32	4.4	3.8	1.8	5.4	1.2
505	6	6.16	4.3	5.3	7.9	13.8	(1.6)
505	6	3.08	3.8	6.2	11.0	18.0	1.2
505	11	3.85	9.7	3.3	6.5	10.4	1.25
520	11	6.16	9.9	4.5	6.2	11.2	2.2
535	11	9.8	10.0	3.5	7.0	11.4	3.6
550	11	15.7	9.8	4.9	6.4	11.8	5.9

TABLE 2

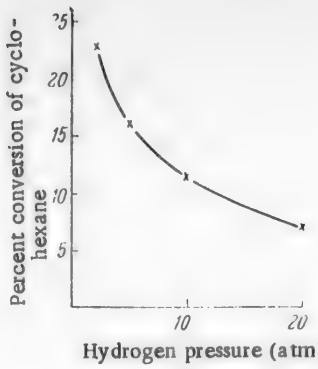
Effect of Cyclohexane Partial Pressure (Chromium catalyst – sample 1, 520°)

Experimental conditions					Analysis results (in weight %)		Cyclohexane reacted (mole %)	$k' \cdot 10^3$
operating pressure (atm)	C_6H_{12} input (mmole per min)	molar ratio $H_2 : C_6H_{12}$	partial pressure (in atm)		unsaturateds	aromatics		
			C_6H_{12}	H_2				
6	6.16	4.7	1.0	5.0	3.5	10.2	14.5	1.9
5.5	3.08	8.5	0.6	4.9	4.9	12.7	18.5	2.3
8	18.48	1.5	3.2	4.8	4.4	9.4	14.5	2.0
9	24.64	1.2	4.1	4.9	4.4	9.5	14.5	2.1
6	6.16	4.8	1.0	5.0	4.6	9.4	14.8	2.0

The effect of volume rate and temperature was studied at a pressure of 6 atm. Examination of the data presented in Table 1 shows that with a decrease in the volume rate, the benzene content of the catalyzate rapidly increased. Simultaneously, there was also an increase in the unsaturated hydrocarbon content, but considerably more slowly. At low degrees of cyclohexane conversion, the amount of unsaturated hydrocarbon formed noticeably exceeded the amount of benzene. With an increase in the degree of conversion, the ratio between the unsaturated hydrocarbon and benzene sharply decreased.

Using the data in Table 1, we calculated the constants k', which remained quite steady while the degree of conversion changed from 5.4 to 42.5%.

To elucidate the effect of temperature on the rate of dehydrogenation, experiments were performed at temperatures of 505, 520, 535 and 550° and a pressure of 11 atm.



Effect of hydrogen pressure on the rate of cyclohexane dehydrogenation.

The average values of the reaction-rate constant gave a good straight line for a plot of log k' against 1/T.

The value found for the apparent activation energy of cyclohexane dehydrogenation on a chromium catalyst was 45,000 cal/mole, i.e., close to the value obtained in experiments at atmospheric pressure [6].

The effect of cyclohexane partial pressure on the reaction rate was studied at 520°. The partial pressure of cyclohexane was varied over the range from 0.6 to 4.1 atm, while the partial pressure of hydrogen was kept constant.

The results obtained are given in Table 2 and show that with a simultaneous and proportional increase in the cyclohexane partial pressure and the volume rate of hydrocarbon input, the degree of conversion remained practically constant. This indicates that the reaction rate is proportional to the partial pressure of cyclohexane.

The fact indicated is reflected in kinetic equation (1), according to which, at a constant hydrogen partial pressure, the reaction rate should increase proportionally to the increase in the cyclohexane partial pressure. The applicability of Equation (1) is confirmed by the fact that the rate constants, calculated by Equation (3), remained quite constant when the cyclohexane partial pressure was changed from 0.6 to 4.1 atm (Table 2).

The effect of hydrogen partial pressure on the reaction rate was studied in a series of experiments at 520°. The experiments were performed at practically constant cyclohexane partial pressure. The hydrogen partial pressure was varied over the range from 1.9 to 20 atm. The results of the experiments are given in Table 3 and illustrated in the figure. Examination of these results leads to the conclusion that the aromatic and unsaturated hydrocarbon content of the catalyzates falls sharply with an increase in the hydrogen partial pressure. Correspondingly, the total amount of cyclohexane conversion also decreased. Thus, when a hydrogen partial pressure of from 1.9 to 20 atm was used, the degree of cyclohexane conversion changed from 22.8 to 7.2%. Hence, the dehydrogenation of cyclohexane is inhibited by hydrogen.

TABLE 3

Effect of Hydrogen Partial Pressure (Chromium catalyst – sample 1, 520°)

Experimental conditions					Analysis results (in weight %)		Cyclohexane reacted (mole %)	$k' \cdot 10^3$
operating pressure in atm.	C_6H_{12} input (mmole per min)	molar ratio $H_2 : C_6H_{12}$	partial pressure (in atm) C_6H_{12}	partial pressure (in atm) H_2	unsaturateds	aromatics		
6	6.16	4.5	1.1	4.9	3.8	11.5	16.1	2.0
3	6.16	1.8	1.1	1.9	6.0	15.8	22.8	2.3
11	6.16	9.0	1.1	9.9	3.9	7.2	11.6	2.1
21	6.16	21.0	1.0	20.0	2.9	4.0	7.2	2.4
6	6.16	4.0	1.2	4.8	3.8	11.5	16.1	2.0

As the data in Table 3 show, the reaction-rate constants, calculated by Equation (3), remain quite constant for this series of experiments also.

SUMMARY

1. A study was made of the reaction kinetics of cyclohexane dehydrogenation on a chromium catalyst (Cr_2O_3/Al_2O_3) at 505-550° and at hydrogen pressures of from 1.9 to 20 atm.

2. It was established that when the cyclohexane partial pressure was changed from 0.6 to 4.1 atm, the reaction rate was proportional to the partial pressure of this hydrocarbon.

3. It was found that increasing the hydrogen partial pressure led to a decrease in the cyclohexane dehydrogenation rate.

4. It was established that the value of the apparent activation energy of cyclohexane dehydrogenation was 45,000 cal/mole.

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ALKYLATION OF ISOPROPYLBENZENE BY PSEUDOBUTYLENE IN THE PRESENCE OF $BF_3 \cdot H_3PO_4$

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In a previous paper [1] it was shown that the molecular compound $BF_3 \cdot H_3PO_4$ was an extremely efficient catalyst for the alkylation of benzene with pseudobutylene. In developing these investigations, we studied the reaction of isopropylbenzene with pseudobutylene in the presence of the same catalyst.

As the investigations showed, pseudobutylene alkylated isopropylbenzene with much more difficulty than benzene under corresponding conditions and the alkylation products were formed in lower yields. The secondary butyl radical was directed to a large extent into the para position. As a result, a mixture of isopropyl-sec-butylbenzenes was formed, consisting of approximately 91% of the para isomer and 9% of the ortho isomer. The relative amount of these in the alkylate was 68-85%. The optimal alkylation conditions, under which the isopropyl-sec-butylbenzenes were obtained in 62-65% yield and a relative content in the alkylate of 80-84%, were a molar ratio of isopropylbenzene, pseudobutylene and catalyst of 3-3.5 : 1 : 0.2-0.3, a temperature of 50-60° and a pseudobutylene input of 1.6-2.5 liters/hour.

Increasing the amount of catalyst to 0.5 mole under the same conditions lowered the yield of isopropyl-sec-butylbenzenes to 52% of the theoretical and their content in the alkylate to 73%. An alkylation with a ratio of reagents and catalyst of 2 : 1 : 0.3 and a temperature of 50° proceeded similarly. The use of more than 3 moles of isopropylbenzene per mole of pseudobutylene gave isopropyl-sec-butylbenzene yields lower than the optimal, even when 0.4 mole of catalyst was used per mole of pseudobutylene.

Temperature had a noticeable effect on the yield of isopropyl-sec-butylbenzenes and the relative amount of them in the alkylate. This effect was studied at isopropylbenzene, pseudobutylene and catalyst ratios of 2 : 1 : 0.2. The alkylation proceeded very slowly at room temperature. Raising the temperature from 20 to 60° accelerated the alkylation process and increased the yield of isopropyl-sec-butylbenzenes, but lowered their relative content in the alkylate due to the accumulation of polyalkylbenzenes in the alkylate. Thus, for example, at 20, 30-35 and 50-60°, the isopropyl-sec-butylbenzenes were obtained in yields of 18, 47 and 55% of theoretical, respectively, and relative contents in the alkylate of 82, 79 and 76%, respectively. At 100° the pseudobutylene was poorly absorbed in the reaction mixture; the catalyst partially decomposed and gradually lost its activity and the isopropyl-sec-butylbenzenes were obtained in very poor yield.

EXPERIMENTAL

The isopropylbenzene used was the freshly distilled technical product with b.p. 149-150°, d_4^{20} 0.8602, and n_D^{20} 1.4910. The preparation of the other starting materials was described previously [1].

Isopropylbenzene was alkylated with pseudobutylene in the apparatus and by the procedure which was used for the alkylation of benzene [1]. The reaction induction period varied from 15 to 25 minutes. After appropriate treatment and drying, the alkylate was distilled separately for each experiment. The isopropyl-sec-butylbenzene fraction was collected over a range of 4-5°. Then the fractions from all the experiments, presented in the Table, were combined and distilled on a column of 25-30 theoretical plates. The isopropyl-sec-butylbenzenes distilled almost completely at 57.5-58.5° at 2 mm. Oxidation of them with 30% nitric acid gave terephthalic and orthophthalic acids in yields of 46.1 and 4.6%, respectively. The terephthalic acid was identified by converting it to its dimethyl ester and the orthophthalic acid as fluorescein.

Alkylation of Isopropylbenzene With Pseudobutylene in the Presence of $BF_3 \cdot H_3PO_4$

Expt. No.	Molar ratios of isopropylbenzene, pseudobutylene and catalyst	Temperature	Rate of pseudobutylene introduction (liters/hr)	Isopropyl-sec-butylbenzenes	
				yield (in %)	relative percent in alkylate
1	5 : 1 : 0.4	20—30°	1.8	31.0	78.5
2	4 : 1 : 0.4	up to 50	2.5	51.9	72.9
3	4 : 1 : 0.2	50—55	2.5	58.3	81.1
4	3.5 : 1 : 0.2	50—60	3.0	65.5	84.1
5	3 : 1 : 0.5	up to 50	1.2	51.9	72.9
6	3.1 : 0 : 0.35	up to 50	1.6	55.4	74.6
7	3 : 1 : 0.3	50—55	1.6	62.1	80.3
8	3 : 1 : 0.3	30—35	1.7	50.9	75.6
9	3 : 1 : 0.2	50—60	3.4	56.4	85.1
10	3 : 1 : 0.1	up to 30	1.6	12.2	73.7
11	2 : 1 : 0.5	50—55	2.6	46.5	74.3
12	2 : 1 : 0.3	up to 50	1.6	52.8	71.8
13	2 : 1 : 0.2	up to 20	2.4	17.7	81.7
14	2 : 1 : 0.2	30—35	1.8	47.4	78.6
15	2 : 1 : 0.2	50—60	3.0	54.9	76.4
16	2 : 1 : 0.2	80	1.8	49.4	73.3
17	2 : 1 : 0.15	up to 40	2.6	40.9	84.6
18	2 : 1 : 0.1	50—60	2.6	32.3	81.1
19	1 : 1 : 0.5	up to 55	2.0	50.3	70.2
20	1 : 1 : 0.3	30—35	1.6	44.1	70.1
21	1 : 1 : 0.3	up to 55	2.4	56.9	78.0
22	1 : 1 : 0.2	up to 60	2.8	42.4	67.7
23	1 : 1 : 0.1	25—30	3.0	27.1	70.2
24	1 : 1 : 0.1	up to 50	2.4	32.6	78.5

On the basis of these data and the assumption that o- and p-isopropyl-sec.-butylbenzenes have the same tendency for oxidation by 30% nitric acid, we can consider that our product was p-isopropyl-sec.-butylbenzene, containing about 9% of o-isopropyl-sec.-butylbenzene. It was a colorless liquid with a pleasant smell.

d_4^{20} 0.8589, n_D^{20} 1.4876, MR_D 59.14; calc. 58.63. Literature data for isopropyl-sec.-butylbenzene, with the position of the alkyl groups not defined [2]: b.p. 223-227°, d_4^{20} 0.8590, n_D^{20} 1.4910.

Found %: C 88.66, 88.66; H 11.46, 11.38. M 176.5, 174.8. $C_{13}H_{20}$. Calculated %: C 88.55; H 11.45; M 176.3.

After autooxidation of 26.5 g of isopropyl-sec.-butylbenzene (first treated with concentrated sulfuric acid) with atmospheric oxygen in the presence of 1 mg of manganese resinate and 80 mg of calcium hydroxide at 110° for 15 hours, 53.9% of hydroperoxides were determined in the reaction mixture iodometrically. Acid cleavage of these hydroperoxides yielded p-isopropylphenol and methyl ethyl ketone. p-Isopropylphenoxyacetic acid was prepared from the p-isopropylphenol and the 2,4-dinitrophenylhydrazone from the methyl ethyl ketone. The constants of these agreed with literature data. The oxidation products of o-isopropyl-sec.-butylbenzene were not detected.

SUMMARY

A study was made of the alkylation of isopropylbenzene with pseudobutylene in the presence of $BF_3 \cdot H_3PO_4$. The effect of different molar ratios of reagents, catalyst concentrations and temperatures in the range 20-100° on the reaction was demonstrated.

Conditions were found under which isopropyl-sec.-butylbenzene was obtained in 62-65% yield. The mixture of isopropyl-sec.-butylbenzenes contained approximately 91% of p- and 9% of o-isopropyl-sec.-butylbenzene.

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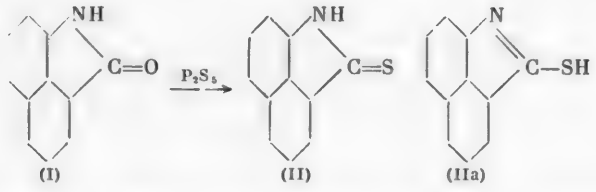
DERIVATIVES OF BENZ-(c,d)-INDOLINE

I. THIONAPHTHOSTYRYL AND N-METHYLTHIONAPHTHOSTYRYL

N.S. Dokunikhin and L.A. Gaeva

The chemistry of benz-(c,d)-indole has been little studied [1]. It has only attracted some attention from investigators recently in connection with determining the structure of lysergic acid – a decomposition product of ergot alkaloids. Unsubstituted benz-(c,d)-indole is unknown. Attempts to synthesize it did not give positive results [2]. Benz-(c,d)-indoline was prepared in 1950 by treating naphthostyryl (I) with $LiAlH_4$ in ethylmorpholine [3]. The latter attracted the attention of investigators as the lactam of 1,8-aminonaphthoic acid – an intermediate in the synthesis of vat dyes of the anthanthrone series [4]. We obtained the thioanalog of naphthostyryl – 2-thionebenz-(c,d)-indoline (II) – previously, by treating 1-naphthyl isothiocyanate with $AlCl_3$ [5]. It seemed interesting to investigate the possibility of another mode of synthesis of this compound and its N-alkyl substituted derivatives, which could not be obtained by isomerization of isothiocyanates.

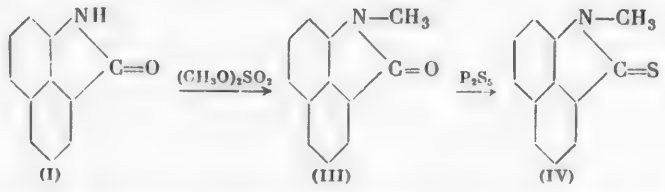
Thionaphthostyryl (II) was obtained from naphthostyryl (I) by heating the latter with P_2S_5 in xylene.



(I) (II) (IIa)

The acid properties shown by thionaphthostyryl indicated that it had the isomeric structure (IIa); however, the infrared spectrum of the crystals showed an absorption band corresponding to NH (ν 3110 cm^{-1}).

Replacement of oxygen by sulfur was also possible for N-methylnaphthostyryl (III). The known method of preparing (III) is by the action of methylamine on 1,8-chloronaphthoic acid [6]. We were able to methylate naphthostyryl directly with dimethyl sulfate in aqueous alkali and with methyl benzenesulfonate in trichlorobenzene.



(I) (III) (IV)

Data on the light absorption of the substances synthesized are given in the Table: solutions in m-xylene were examined on an SF-4 spectrophotometer.

Replacement of the oxygen by sulfur produced an intense absorption band with a maximum at about 435 mμ and the absorption band with a maximum at 320 mμ disappeared.

Substance	λ_{max} mμ	ε · 10⁻⁴	λ_{max} mμ	ε · 10⁻⁴	λ_{max} mμ	ε · 10⁻⁴	λ_{max} mμ	ε · 10⁻⁴	λ_{max} mμ	ε · 10⁻⁴
(I)			320	0.25	335	0.35	359	0.35		
(II)	290	0.65					360	0.46	434.5	0.95
(III)	290	0.37	320	0.22	335	0.29	370	0.28		
(IV)	300	0.68			343	0.33	360	0.52	435	1.11

EXPERIMENTAL

Thionaphthylstyryl [2-thionebenz-(c,d)-indoline]. 2.5 g of naphthostyryl and 3.2 g of phosphorus pentasulfide in 60 ml of xylene were stirred for three hours at 130°, cooled and filtered. The filtrate (in several portions) was treated with 500 ml of 2% aqueous NaOH. The thionaphthostyryl was isolated from the aqueous layer with hydrochloric acid. The yield was 1.84 g (67.2%) and the m.p. 152-157°. After recrystallization from benzene, the substance had m.p. 156.6-157.6°. It was identical with the substance obtained from 1-naphthyl isocyanate [5].

N-Methylnaphthostyryl [1-methylbenz-(c,d)-indolin-2-one]. 5.0 g of naphthostyryl was added to a solution of 12 g of NaOH in 50 ml of water. Over a period of two hours, 14 ml of dimethyl sulfate was added at 40-42°, the mixture was stirred for a further one hour and the product filtered and washed with water. The greasy precipitate was dissolved in ether, separated from the water and dried and the ether evaporated. The residue (about 5 ml) was cooled, filtered and the precipitate recrystallized from benzine. The yield of (III) was 1.65 g (30.4%) and the m.p. 77.0-79.2° (72-75° [6]).

Found %: C 78.47, 78.68; H 4.95, 4.81; N 7.41, 7.31. $C_{12}H_9ON$. Calculated %: C 78.68; H 4.91; N 7.65.

5.0 g of naphthostyryl and 9.0 g of K_2CO_3 in 25 ml of trichlorobenzene was heated to 150° and a mixture of 15 ml of methyl benzenesulfonate and 15 ml of trichlorobenzene added over a period of four hours. The mixture was filtered and the trichlorobenzene distilled from the filtrate in steam. The residue was extracted with ether and dried and the ether distilled off completely. The yield of (III) was 1.7 g (31.3%). After recrystallization from 15 ml of benzine, the substance had m.p. 77.8-79.8°.

N-Methylthionaphthostyryl [1-methyl-2-thionebenz-(c,d)-indoline] (IV). 1.65 g of N-methylnaphthostyryl and 2.0 g of phosphorus pentasulfide in 30 ml of xylene were stirred at 130° for four hours. The reaction mixture was filtered, half the xylene distilled off from the filtrate, the precipitated tars separated and the xylene distilled off completely. The residue (1.1 g) melted at 90-120°. After two recrystallizations from alcohol, the yellow needles had m.p. 127.2-130.4°.

Found %: C 71.91, 71.81; H 4.47, 4.62; N 6.77, 6.84; S 16.04. $C_{12}H_9NS$. Calculated %: C 72.36; H 4.53; N 7.03; S 16.08.

We would like to thank D.N. Shigorin and E.S. Levin for the optical measurements.

SUMMARY

1. Treatment of naphthostyryl and N-methylnaphthostyryl with phosphorus pentasulfide gave thionaphthostyryl and N-methylthionaphthostyryl.

2. N-Methylnaphthostyryl was prepared by methylation of naphthostyryl.

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THE PREPARATION OF o-NITROSOPHENOL FROM SALICYLIC ACID

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o-Nitrosophenol is a valuable analytical reagent for the determination of copper [1-3], cobalt [4] and divalent iron [5]. The methods of determining the elements listed using o-nitrosophenol are distinguished by high selectivity and great sensitivity. For example, in determining Fe^{II} with o-nitrosophenol, the sensitivity is three times greater than the determination with α,α'-dipyridyl [5]. There are also reports of the successful use of o-nitrosophenol for determining mercury, nickel, palladium and zinc [5, 6].

The difficulty of its preparation is an obstacle to the wide use of o-nitrosophenol as an analytical reagent.

o-Nitrosophenol was first prepared by Baeyer and Knorr [7] from o-nitrosoanisole by hydrolyzing it with boiling $KHSO_4$ solution. Due to the low yield of o-nitrosophenol and the poor availability of the starting o-nitrosoanisole, a series of attempts was made to prepare o-nitrosophenol by other methods. In particular, preparations were put forward for o-nitrosophenol from the p-toluenesulfonic ester of o-nitrophenol [8] and then from o-nitroanisole [1] by treatment with amyl nitrite in an aqueous alcohol solution in the presence of ammonia and zinc dust. The o-methoxynitrosophenylhydroxylamine formed precipitated as a complex copper salt, which was treated with lime in boiling xylene and, after acidification of the mixture, the o-nitrosophenol formed was extracted with petroleum ether.

o-Nitrophenol was also proposed as a starting material for the preparation of o-nitrosophenol [2]. Later, a series of variations was proposed for the preparation of o-nitrosophenol directly from benzene [9-11] using copper acetate, potassium nitrite and hydrogen peroxide or ammonium pentacyanoferroate, hydroxylamine and hydrogen peroxide.

Although these methods differed from the preceding ones in great simplicity and ready availability of starting materials, as before, their fault was the insignificant yield of o-nitrosophenol.

A preparation for o-nitrosophenol is also described – by treatment of phenol with hydroxylamine hydrochloride in the presence of copper acetate and hydrogen peroxide [12]. The main reaction product in this case is p-nitrosophenol and only an insignificant amount of o-nitrosophenol is formed.

The author recently showed that when salicylic acid was treated with nitrous acid in an acetic acid medium, a nitroso group was introduced into the salicylic acid in place of the carboxyl group with the evolution of CO_2 and the formation of o-nitrosophenol, which then reacted with the nitrous acid to form o-diazophenol, the main reaction product [13]. Such a course of the reaction is explained by the fact that the stage of o-nitrosophenol formation is slower than the subsequent conversion to o-diazophenol. If the reaction is performed in the presence of copper salts, then the o-nitrosophenol immediately reacts with the Cu^{II} and is bound as a stable copper complex salt. In contrast to o-nitrosophenol itself, the complex shows no tendency for further reaction with nitrous acid.

In addition, o-nitrosophenol is not stable in aqueous solutions, while its complex copper salt has quite high stability. Due to this, almost all the o-nitrosophenol is accumulated in the reaction mixture as the complex copper salt. At the end of the reaction, the complex copper salt of o-nitrosophenol is decomposed with dilute hydrochloric acid and the free o-nitrosophenol extracted with petroleum ether. Saturation of the extract with ammonia gas precipitates the o-nitrosophenol as the ammonium salt. The o-nitrosophenol yield is about 65%. Up to 10% of 5-diazosalicylic acid (calculated on the original salicylic acid) was found among the reaction products. Thus, the nitrosation of the complex copper salt of salicylic acid is different from that of the complex

aluminum, chromium and zinc salts of salicylic acid, described previously [14]. In comparison with these, the complex copper salt of salicylic acid has considerably less reactivity in nitrosation reactions. Nitrosation of the complex copper salt of salicylic acid is more similar to nitrosation of free salicylic acid. The difference is only that in this case, the o-nitrosophenol formed combines immediately with Cu^{II} in a stable complex compound, in which the nitroso group is shielded from further reaction with nitrous acid. On the other hand, in the complex copper salt of 5-nitrososalicylic acid formed, the nitroso group is not shielded from further reaction with nitrous acid and hence it is readily converted into the complex copper salt of 5-diazosalicylic acid. Since the complex copper salt of 5-nitrososalicylic acid is formed very slowly from the complex copper salt of salicylic acid and then its conversion into the complex copper salt of 5-diazosalicylic acid proceeds at a considerably greater rate, the content of complex copper salt of 5-nitrososalicylic acid of the reaction mixture does not exceed 2%, calculated on the original salicylic acid.

Papers stating that 5-nitrososalicylic acid is formed in 97% yield by treatment of the complex copper salt of salicylic acid with nitrous acid [15-17] are incorrect.

EXPERIMENTAL

Preparation of o-nitrosophenol. 4 g of sodium salicylate was dissolved in 50 ml of water and 5 g of $NaNO_2$ was added, followed by 10 g of copper sulfate, dissolved in 50 ml of water and 2.5 ml of glacial acetic acid. The yellow-green solution was heated to 50-55° and kept at this temperature for six hours. The solution color changed from yellow-green and became an intense red. At the same time a dark-red precipitate formed. The reaction mixture was kept at 20-25° for 12 hours. Then 20 ml of a 10% sulfamic acid solution was added to remove the unreacted nitrous acid. After 5-10 minutes, 50 ml of dilute (1:1) hydrochloric acid was added to decompose the complex copper salt of o-nitrosophenol formed. The latter was extracted with petroleum ether (3·50 ml). The ether extract was washed twice with water to remove traces of hydrochloric acid. The solution of o-nitrosophenol obtained was quite pure and could be used directly for analytical purposes.

The solution of o-nitrosophenol in petroleum ether could be stored at room temperature without noticeable change for 3-4 days and at 0° for up to two weeks. The o-nitrosophenol itself could not be isolated in a large amount as it decomposed extremely rapidly, going partly to o-nitrophenol and partly to unknown products. In addition, due to its extremely high volatility, a considerable part of it was lost during the evaporation of the petroleum ether. After evaporation of a petroleum ether solution of o-nitrosophenol on a clock glass, light, greenish-yellow needle-like crystals of pure o-nitrosophenol were left and these had a characteristic sharp smell. To determine the o-nitrosophenol yield, the substance was extracted completely with petroleum ether (until there was no longer a positive reaction when 1% copper sulfate solution was added to 0.5-1 ml of extract). The whole extract was collected in a graduated flask of 250-ml capacity and made up to the mark with petroleum ether. 5 ml of 1 N NaOH solution was added to 10 ml of the organic solution, the mixture shaken thoroughly and the aqueous layer separated. The extraction was repeated with a fresh portion of NaOH. The o-nitrosophenol content of the aqueous solution obtained was determined by titration with vanadous sulfate [17]. The yield of o-nitrosophenol was 65%, calculated on the sodium salicylate.

By reaction with alkaline solutions of resorcinol and 1,8-aminonaphthol-3,6-disulfonic acid to form the azo dyes, it was established that the reaction mixture, after separation of the o-nitrosophenol, contained a diazo compound. The diazo compound was determined quantitatively by Hantzsch's method [18]. For this, the reaction mixture (after separation of the o-nitrosophenol) was transferred to a 250-ml graduated flask and diluted to the mark with water and 25 ml of this solution (solution A) was used for each determination. The amount of diazo compound found was 9.4% (calculated on the sodium salicylate).

When 50 ml of solution A (first neutralized with soda was treated with 0.8 g of resorcinol) dissolved in 10 ml of 10% soda solution, the azo dye formed was extracted with ethyl ether after acidification and then the ether extract obtained passed through a column filled with chromatographic grade aluminum oxide, two different azo compounds were obtained. One of these was identified by the light absorption curve in aqueous solutions as 2,2',4-trihydroxyazobenzene and the other as 2,4,4'-trihydroxyazobenzene-3'-carboxylic acid. The yields of these, determined by titration with VSO_4 solution [17], were 2.7 and 6.9%, respectively, calculated on the sodium salicylate.

A nitroso compound, which differed from o-nitrosophenol in that it was not extracted with petroleum ether, but was readily extracted with ethyl ether, was detected in solution A by a well-known, qualitative test [9]. It

was isolated from the mixture by chromatography of the ether solution on aluminum oxide. The amount of it, determined according to [17], was 1.2% (calculated on the sodium salicylate). After reduction with zinc dust in hydrochloric acid, the amino compound formed was diazotized and coupled with resorcinol. The azo compound obtained was identified by the light absorption curve as 2,4,4'-trihydroxyazobenzene-3-carboxylic acid. Consequently, when the complex copper salt of salicylic acid was treated with nitrous acid under the conditions described, it yielded 65% of o-nitrosophenol, 2.7% of o-diazophenol, 9.6% of diazosalicylic acid and 1.2% of 5-nitrososalicylic acid, calculated on the salicylic acid.

Preparation of o-nitrosophenol ammonium salt. The solution of o-nitrosophenol in petroleum ether obtained was put into a dish and placed in a desiccator containing a small amount of concentrated ammonia solution. When the o-nitrosophenol had been converted into the ammonium salt completely (indicated by decolorization of the petroleum ether), the red precipitate of the ammonium salt of o-nitrosophenol was filtered off and washed with petroleum ether. The yield was 2.25 g.

Found %: C 51.30; H 5.70; N 19.85. $C_6H_8O_2N_2$. Calculated %: C 51.43; H 5.76; N 20.00

Preparation of complex copper salt of o-nitrosophenol. The complex copper salt of o-nitrosophenol was prepared as described above, with the difference that after the nitrosation reaction, the precipitate of the complex copper salt of o-nitrosophenol was not decomposed by the addition of hydrochloric acid, but was filtered off and washed with a small amount of cold water, then with alcohol and finally with ether. In comparison with o-nitrosophenol itself and its ammonium salt, the complex copper salt of o-nitrosophenol was considerably more stable. No signs of deterioration were detected when it was stored for 14 months. To prepare a solution in petroleum ether from it, it was treated with 4-6% hydrochloric acid and the liberated o-nitrosophenol extracted with petroleum ether.

A test was carried out for the formation of nitrososalicylic acid using Gulinov's method [15, 16], according to which 16 g of sodium salicylate was dissolved in 450 ml of water, a solution of 25-35 g of copper sulfate and 7 g of sodium nitrite in 150 ml of water added and the reaction mixture left for 9-10 days. The precipitate was filtered off and washed with a small amount of water, then with alcohol and ether. The precipitate was treated with 4-6% hydrochloric acid and then extracted with petroleum ether to isolate o-nitrosophenol. The latter was identified by analysis and the characteristic reaction colors with Fe^{II}, Co and Cu. By the method described above, the residue after separation of the o-nitrosophenol was shown to contain 1.9% of 5-nitrososalicylic acid, 5.4% of the 5-diazosalicylic acid and 0.7% of o-diazophenol (calculated on sodium salicylate).

SUMMARY

A method was developed for preparing o-nitrosophenol from salicylic acid by the action of sodium nitrite in acetic acid solution in the presence of cupric salts, which form a stable complex salt with o-nitrosophenol and shield it from further reaction with nitrous acid, which converts it to o-diazophenol.

The method described for the preparation of o-nitrosophenol differs from methods described up to now in its exceptional simplicity, the availability of the starting materials and the high yield.

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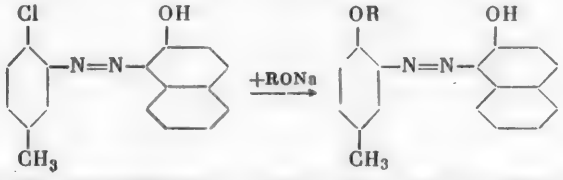
THE REPLACEMENT OF HALOGEN IN AZO COMPOUNDS

IV. THE REPLACEMENT OF CHLORINE IN 5-METHYL-2-CHLOROBENZENEAZO-2'-NAPHTHOL BY ALKOXY AND AROXY GROUPS AND THE PREPARATION OF ETHERS OF 3-AMINO-4-HYDROXYTOLUENE

B.I. Stepanov

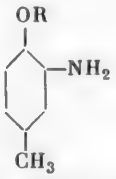
In extending the method of replacing the halogen in o-halo-o'-hydroxyazo dyes, which was tested on 2-chlorobenzeneazo-2'-naphthol [1-3], to other examples, we prepared a series of azo dyes – derivatives of ethers of 3-amino-4-hydroxytoluene – from 5-methyl-2-chlorobenzeneazo-2'-naphthol.



R=C_2H_5, n.-C_4H_9, $(CH_3)_2CHCH_2CH_2$, n.-C_8H_{13}, n.-C_9H_{17}, n.-$C_{13}H_{27}$, $C_6H_5CH_2$, $C_6H_5CH_2CH_2$, $C_6H_5CH_2CH_2CH_2$, C_6H_5, 3,5-$(CH_3)_2C_6H_3$, &4-$(CH_3)_3CCH_2C(CH_3)_2C_6H_4$.

The reaction with the alcoholates was more convenient to perform in a mixture of the corresponding alcohol and with an inert solvent (toluene or xylene). In this case, the consumption of alcohol was reduced and the reaction product was more readily isolated and purified. The dyes with alkoxy and aroxy groups obtained were capable of coloring acetate and polyamide fibers.

Reductive cleavage of the dyes obtained gave a series of ethers of 3-amino-4-hydroxytoluene.



R=n-C_4H_9, $(CH_3)_2CHCH_2CH_2$, n.-C_8H_{13}, n-C_9H_{17}, n.-$C_{13}H_{27}$, $C_6H_5CH_2CH_2$, $C_6H_5CH_2CH_2CH_2$, 3,5-$(CH_3)_2C_6H_3$.

EXPERIMENTAL

The starting azo dye was prepared by diazotizing 3-amino-4-chlorotoluene (m.p. 29-30°) and coupling the product with 2-naphthol. After recrystallization from toluene, the reddish-orange, lustrous needles had m.p. 163.5-164°. The dye was soluble in toluene, chlorobenzene and glacial acetic acid, less soluble in methyl and ethyl alcohols and insoluble in water. A solution in concentrated sulfuric acid had a crimson color, which became orange when the solution was diluted with water.

Found %: C 68.39, 68.58; H 4.44, 4.53; N 9.27, 9.35. $C_{17}H_{13}ON_2Cl$. Calculated %: C 68.80; H 4.38; N 9.52.

Replacement of chlorine by alkoxy groups.* 4 g of starting dye was triturated with 2 g of copper sulfate and a solution of sodium alcoholate, prepared from 1 g of metallic sodium and 20 ml of the appropriate alcohol: ethyl, n-butyl (b.p. 117°), isoamyl (2-methylbutanol-4, b.p. 132°), n-hexyl (b.p. 157°), n-octyl (b.p. 194-195°), benzyl (b.p. 204-206°), β-phenylethyl (b.p. 219-221° at 750 mm), and γ-phenylpropyl (b.p. 235-237°). The mixture obtained was diluted with 20 ml of toluene and heated and stirred for 10-12 hours at 100-110° (in the case of ethyl alcohol – heated on a water bath with a temperature of 74-75° inside the flask). In the case of n-octadecyl alcohol (m.p. 58.5°), the alcoholate was prepared by reacting 20 g of the alcohol with 1 g of metallic sodium at 150-160°, the solution of octadecylate cooled to 95° and a suspension of copper sulfate (2 g) in a solution of the starting dye (4 g) in toluene (20 ml) added to it.

After the heating, the toluene and the excess of the appropriate alcohol was distilled away in vacuum, the residue diluted with water and the residue filtered off (in the case of octadecyl alcohol the excess was removed by washing with hot methyl alcohol). The residue was then boiled with concentrated hydrochloric acid, the mass diluted with water, filtered, washed free from chloride ion and dried in air. A test for chlorine was negative.

We obtained 3.52 g (85.4%) of the ethoxy-substituted dye. After recrystallization from glacial acetic acid, the coarse needles had m.p. 184.5°. The dye was readily soluble in benzene, toluene, chloroform and carbon tetrachloride in the cold and in acetone and glacial acetic acid on heating; it was almost insoluble in methyl and ethyl alcohols in the cold, dissolved slightly in methyl alcohol on heating and slightly more in ethyl alcohol and was insoluble in water.

Found %: N 9.14. $C_{19}H_{18}O_2N_2$. Calculated %: N 9.15.

We obtained 4.4 g (97.7%) of the butoxy-substituted dye. After recrystallization from glacial acetic acid, the tufts of fine, lustrous needles had m.p. 139°. The product was readily soluble in benzene, toluene and chloroform in the cold and in acetone, glacial acetic acid and carbon tetrachloride on heating; it was difficultly soluble in methyl alcohol, even on heating, slightly more soluble in ethyl alcohol on heating and insoluble in water.

Found %: C 75.36, 75.23; H 6.61, 6.76; N 8.46, 8.26. $C_{21}H_{22}O_2N_2$. Calculated %: C 75.45; H 6.59; N 8.38.

We obtained 3.82 g (81.5%) of the 3-methylbutoxy-substituted dye. After recrystallization from acetone, the long needles had m.p. 142.5°. The material was readily soluble in benzene, toluene, chloroform and carbon tetrachloride in the cold, less soluble in acetone, dissolved in methyl and ethyl alcohols on heating and was insoluble in water.

Found %: C 75.43, 75.55; H 7.38, 7.31; N 7.86, 7.98. $C_{22}H_{24}O_2N_2$. Calculated %: C 75.86; H 6.89; N 8.05.

3.1 g (63.5%) of the hexoxy-substituted dye was obtained. After recrystallization from glacial acetic acid, the lustrous needles had m.p. 110°. The product was readily soluble in benzene, toluene, chlorobenzene, chloroform and carbon tetrachloride in the cold and in methyl and ethyl alcohols, glacial acetic acid and acetone on heating; it was insoluble in water.

Found %: C 76.47, 76.33; H 7.41, 7.59; N 7.80, 7.61. $C_{23}H_{26}O_2N_2$. Calculated %: C 76.22; H 7.18; N 7.73.

3.77 g (71.6%) of the octoxy-substituted dye was obtained. After recrystallization from ethyl alcohol, the overgrown needles had m.p. 114°. The product was readily soluble in benzene, toluene and chloroform in the cold and in methyl and ethyl alcohols, acetone and carbon tetrachloride on heating; it was insoluble in water.

Found %: C 77.10, 77.20; H 7.76, 7.89; N 7.38, 7.32. $C_{25}H_{30}O_2N_2$. Calculated %: C 76.92; H 7.69; N 7.18.

4.68 g (65.1%) of the octadecoxy-substituted dye was obtained. After recrystallization from ethyl alcohol, the fine needles had m.p. 82°. The product was readily soluble in benzene, toluene, acetone, chloroform and carbon tetrachloride in the cold, in glacial acetic acid on heating and slightly less in methyl and ethyl alcohols; it was insoluble in water.

*With the participation of L.B. Iurkov.

Found %: C 79.06, 79.13; H 9.39, 9.49; N 5.48. $C_{35}H_{50}O_2N_2$. Calculated %: C 79.24; H 9.43; N 5.28.

3.17 g (63.9%) of the phenylmethoxy-substituted dye was obtained. After recrystallization from acetone, the long needles had m.p. 175°. The product was readily soluble in benzene, toluene and chloroform in the cold and less soluble in acetone, but readily so on heating, and less so in methyl and ethyl alcohols and carbon tetrachloride; it was insoluble in water.

Found %: C 77.99, 78.11; H 5.54, 5.68; N 7.77, 7.71. $C_{24}H_{20}O_2N_2$. Calculated %: C 78.26; H 5.43; N 7.61.

4.11 g (79.8%) of the β-phenylethoxy-substituted dye was obtained. After recrystallization from glacial acetic acid, the needles had m.p. 169.5-170°. The substance was soluble in benzene, toluene, chlorobenzene, chloroform and carbon tetrachloride in the cold and on heating it dissolved readily in acetone and glacial acetic acid and sparingly in methyl and ethyl alcohols; it was insoluble in water.

Found %: C 78.34, 78.26; H 6.02, 5.99; N 7.53. $C_{25}H_{22}O_2N_2$. Calculated %: C 78.53; H 5.76; N 7.33.

4.1 g (76.7%) of the γ-phenylpropoxy-substituted dye was obtained. After recrystallization from ethyl alcohol, the fine needles had m.p. 138°.

Found %: C 78.99, 78.80; H 6.22, 6.12; N 7.26, 7.07. $C_{26}H_{24}O_2N_2$. Calculated %: C 78.78; H 6.06; N 7.07.

Replacement of chlorine by the phenoxy group.* 4 g of the starting dye, ground up with 2 g of copper sulfate, was added to a solution of phenolate prepared by reacting 20 g of phenol with 30 ml of 30% sodium hydroxide solution, and the mixture heated under reflux with stirring for ten hours at 110°. The reaction mixture was then filtered and the precipitate washed, first with 5% sodium hydroxide solution to remove excess phenol and then with water, and boiled with 70 ml of concentrated hydrochloric acid. The mixture was diluted with water and the dye filtered off, washed free from ionic chlorine and dried at 70°. The weight was 4.1 g (85.9%). A test for chlorine was negative. After recrystallization from acetone, the flat needles had m.p. 169.5-170°. A mixture with the starting dye (m.p. 163.5-164°) had a depressed melting point (to 140-146°). In the cold, the phenoxy-substituted dye was readily soluble in benzene, toluene, chlorobenzene, chloroform and carbon tetrachloride and poorly so in methyl and ethyl alcohols and acetone; on heating, it dissolved slightly more in methyl and ethyl alcohols and readily in acetone; it was insoluble in water.

Found %: C 77.62, 77.75; H 5.89, 6.03; N 7.61. $C_{23}H_{18}O_2N_2$. Calculated %: C 77.96; H 5.08; N 7.91.

Replacement of chlorine by the 3,5-dimethylphenoxy group. 4 g of the starting dye, ground with 2 g of copper sulfate, was added to a solution of xylenolate, prepared by reacting 5 g of 1,3,5-xylenol with 11 g of 16.5% sodium hydroxide solution and the mixture heated under reflux with stirring for ten hours at 105-110°. The reaction mixture was diluted with water, and the precipitate filtered off, washed free from excess xylenol with 5% sodium hydroxide solution and then water and boiled with 50 ml of concentrated hydrochloric acid. The mixture was diluted with water and the dye filtered off, washed free from ionic chlorine and dried in air. The weight was 4.75 g (92.6%). A test for chlorine was negative. After recrystallization from glacial acetic acid, the flat needles had m.p. 163.5-164°. A mixture with the starting dye (m.p. 163.5-164°) had a depressed melting point (to 139°). The 3,5-dimethylphenoxy-substituted dye was readily soluble in benzene, toluene, acetone, chloroform and carbon tetrachloride and slightly less so in glacial acetic acid; it dissolved sparingly in ethyl alcohol in the cold, but readily on heating, was insoluble in methyl alcohol in the cold and dissolved sparingly on heating and did not dissolve in water.

Found %: C 78.57, 78.45; H 5.90, 5.99; N 7.46. $C_{25}H_{22}O_2N_2$. Calculated %: C 78.53; H 5.76; N 7.33.

Replacement of chlorine by the 4-(1',1',3',3'-tetramethylbutyl)-phenoxy group (p-isooctylphenoxy group). 3 g of the starting dye, ground with 1.5 g of copper sulfate, was added to a mixture of isooctylphenolate and xylene, prepared by reacting 7 g of 4-isooctylphenol with 0.7 g of metallic sodium in 30 ml of xylene with heating. The mixture formed was heated under reflux with stirring for 16 hours at 105-110° and then the xylene distilled off in vacuum at 90°. The residue was boiled several times with 5% sodium hydroxide solution to remove the excess isooctylphenol, washed with water and boiled with 50 ml of concentrated hydrochloric acid. The

*V.S. Zenkevich participated in the experiments with phenolates.

mixture was diluted with water and the dye filtered off, washed free from ionic chlorine and dried at 80°. The weight was 4.65 g (98.7%). A test for chlorine was negative. After recrystallization from glacial acetic acid, the bunches of fine needles had m.p. 171-172°. The isooctylphenoxy-substituted dye was readily soluble in benzene, toluene, chloroform, carbon tetrachloride and acetone in the cold, and in glacial acetic acid and ethyl alcohol on heating; it was sparingly soluble in methyl alcohol and insoluble in water.

Found %: C 79.63, 79.57; H 7.38, 7.48; N 6.18. $C_{31}H_{34}O_2N_2$. Calculated %: C 79.82; H 7.29; N 6.00.

Preparation of ethers of 3-amino-4-hydroxytoluene. 2 g of the appropriate alkoxy or aroxy substituted azo dye (see above) was reduced by boiling with a solution of stannous chloride (prepared by reacting 3 g of metallic tin with 30 ml of concentrated hydrochloric acid with heating and by diluting with 30 ml of water before introducing the dye) under reflux until it was decolorized. The following day, the inhomogeneous precipitate, which formed overnight, was filtered off and treated with 50 ml of 5% sodium hydroxide solution, containing 0.75 g of sodium hydrosulfite, and then the 3-amino-4-alkoxy-(or aroxy)-toluene extracted several times with ether (a total volume of about 50 ml). The ether layer was separated and treated with 1 ml of concentrated hydrochloric acid and the precipitate of the amine hydrochloride filtered off, dried in air and purified by recrystallization.

To prepare the N-benzoyl derivatives, 0.1 g of the amine hydrochloride was treated with 2 ml of 20% sodium hydroxide solution and 0.5 ml of benzoyl chloride. The benzoyl derivative was washed with water, triply diluted hydrochloric acid and again with water, dried in air and recrystallized from methyl alcohol.

1.14 g (88.4%) of 3-amino-4-butoxytoluene hydrochloride was obtained. After recrystallization from water acidified with several drops of hydrochloric acid, the fine needles had m.p. 169°.

The N-benzoyl derivative of 3-amino-4-butoxytoluene formed long needles with m.p. 67°.

Found %: C 76.23, 76.18; H 7.73, 7.64; N 4.68, 4.58. $C_{18}H_{21}O_2N$. Calculated %: C 76.32; H 7.42; N 4.94.

1.23 g (93.1%) of 3-amino-4-(3'-methylbutoxy)-toluene hydrochloride was obtained. After recrystallization from water, acidified with several drops of hydrochloric acid (with preliminary decoloration of the solution with activated charcoal), the fine, branched filaments had m.p. 168°.

The N-benzoyl derivative of 3-amino-4-(3'-methylbutoxy)-toluene formed fine needles with m.p. 72°.

Found %: N 4.60, 4.51; $C_{19}H_{23}O_2N$. Calculated %: N 4.71.

1.2 g (96%) of 3-amino-4-hexoxytoluene hydrochloride was obtained. After recrystallization from water acidified with several drops of hydrochloric acid, the long needles melted at 171°.

Found %: C 63.93, 63.86; H 9.30, 9.40; N 5.83, 5.90. $C_{13}H_{22}ONCl$. Calculated %: C 64.06; H 9.03; N 5.77.

The N-benzoyl derivative of 3-amino-4-hexoxytoluene formed long needles with m.p. 73°.

Found %: C 76.59, 76.45; H 8.19, 8.22; N 4.33, 4.25. $C_{20}H_{25}O_2N$. Calculated %: C 77.17; H 8.04; N 4.50.

1.13 g (89.3%) of 3-amino-4-octoxytoluene hydrochloride was obtained. After recrystallization from dilute hydrochloric acid with a small amount of methyl alcohol added, the long needles had m.p. 125-125.5°.

Found %: C 66.64, 66.50; H 9.57, 9.74; N 4.92, 5.00. $C_{15}H_{22}ONCl$. Calculated %: C 66.29; H 9.57; N 5.15.

0.74 g (47.7%) of 3-amino-4-octadecoxytoluene hydrochloride was obtained. After recrystallization from dilute methyl alcohol acidified with several drops of hydrochloric acid, the fine needles had m.p. 119-120°.

Found %: C 72.87, 73.02; H 11.65, 11.40; N 3.97, 3.81. $C_{25}H_{46}ONCl$. Calculated %: C 72.90; H 11.18; N 3.40.

The N-benzoyl derivative of 3-amino-4-octadecoxytoluene formed fine, flat needles with m.p. 61°.

Found %: C 79.86, 79.99; H 10.64, 10.72; N 2.85, 2.83. $C_{32}H_{49}O_2N$. Calculated %: C 80.16; H 10.23; N 2.92.

1.27 g (91.8%) of 3-amino-4-(β-phenylethoxy)-toluene hydrochloride was obtained. After recrystallization from dilute methyl alcohol, the balls of fine needles had m.p. 167-177° (with decomp.) and 187-188.5° (in a sealed capillary).

Found %: C 68.87, 68.78; H 6.85, 6.90; N 5.84, 5.92. $C_{15}H_{18}ONCl$. Calculated %: C 68.31; H 6.83; N 5.31.

The N-benzoyl derivative of 3-amino-4-(β-phenylethoxy)-toluene formed long lustrous flat needles with m.p. 92.5-93°.

Found %: C 79.86, 79.73; H 6.44, 6.56; N 4.51, 4.62. $C_{22}H_{21}O_2N$. Calculated %: C 79.76; H 6.34; N 4.23.

1.04 g (74.3%) of 3-amino-4-(γ-phenylpropoxy)-toluene hydrochloride was obtained. After recrystallization from dilute methyl alcohol acidified with several drops of hydrochloric acid, the fine, branched needles had m.p. 159-160°.

The N-benzoyl derivative of 3-amino-4-(γ-phenylpropoxy)-toluene formed long, flat needles with m.p. 85-85.5°.

Found %: C 80.25, 80.32; H 6.66, 6.86. $C_{23}H_{23}O_2N$. Calculated %: C 80.00; H 6.67.

1.3 g (94.6%) of 3-amino-4-(3',5'-dimethylphenoxy)-toluene hydrochloride was obtained. After recrystallization from methyl alcohol acidified with several drops of hydrochloric acid, the long, flat needles had m.p. 163-163.5°.

Found %: C 68.11, 67.97; H 7.00, 7.20. $C_{15}H_{18}ONCl$. Calculated %: C 68.31; H 6.83.

The N-benzoyl derivative of 3-amino-4-(3',5'-dimethylphenoxy)-toluene formed fine needles with m.p. 146.5-146.7°.

SUMMARY

1. On reacting sodium alcoholates and phenolates with the azo dye from 3-amino-4-chlorotoluene and 2-naphthol in the presence of a copper salt, the chlorine atom was replaced by the alkoxy and aroxy groups with ethyl, n-butyl, isoamyl (3-methylbutyl), n-hexyl, n-octyl, n-octadecyl, benzyl, β-phenylethyl, γ-phenylpropyl, phenyl, 3,5-dimethylphenyl and 4-(1',1',3',3'-tetramethylbutyl)-phenyl (p-isooctylphenyl) residues.

2. It was found that the reaction of the halogen-containing dye and the alcoholate could be performed more conveniently in a mixture of the appropriate alcohol and an inert solvent (toluene or xylene).

3. Reductive cleavage of the alkoxy and aroxy substituted dyes gave ethers of 3-amino-4-hydroxytoluene with n-butyl, isoamyl (3-methylbutyl), n-hexyl, n-octyl, n-octadecyl, β-phenylethyl, γ-phenylpropyl and 3,5-dimethylphenyl residues in the ether group.

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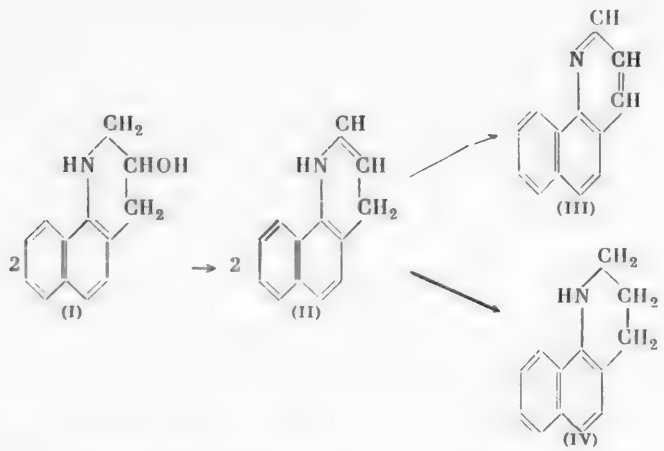
INVESTIGATION OF THE PRODUCTS FROM THE REACTION OF EPICHLOROHYDRIN AND AROMATIC AMINES

III. THE ACTION OF HYDROCHLORIC ACID AND THIONYL CHLORIDE ON 3-HYDROXY-1,2,3,4-TETRAHYDRO-7,8-BENZOQUINOLINE AND ON 3-HYDROXY-1,2,3,4-TETRAHYDRO-5,6-BENZOQUINOLINE

N.N. Vorozhtsov, Jr. and S.I. Kutkevichus

We undertook an investigation of the action of hydrochloric acid and thionyl chloride on 3-hydroxy-1,2,3,4-tetrahydro-7,8-benzoquinoline (I) (see [1] for preparation), so as to replace the hydroxyl group by a chlorine atom. However, the action of these reagents on (I) did not lead to the required result. When (I) was heated (to 170-200°) with hydrochloric acid under pressure, we obtained a mixture of two bases, which did not contain halogen, and one of them was 7,8-benzoquinoline (III) (42-44% yield) and the other its 1,2,3,4-tetrahydro derivative (IV) (27 to 33%).

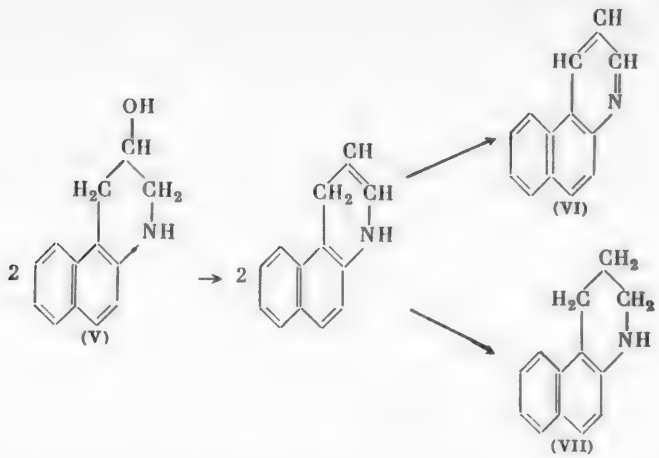
Apparently, this conversion began with the elimination of a molecule of water to form the 1,2- or 1,4-dihydro derivative of benzoquinoline (II), which then disproportionated into benzoquinoline (III) and its tetrahydro derivative (IV).



We attempted to prepare 1,2,3,4-tetrahydro-7,8-benzoquinoline as the main product by reduction of (I) by heating it with hydriodic acid (in the presence of acetic acid) at 200-210°. However, we were only able to isolate substance (III) (27% yield) from the reaction products. It is probable that in this case a mixture of (III) and (IV) was formed first. The latter, however, decomposed under these conditions. The instability of (IV) has been noted previously [2].

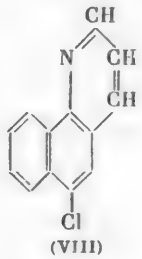
Conversion into the corresponding quinoline and its tetrahydro derivative under the action of hydrochloric acid is not peculiar to (I) only, but apparently is characteristic of 3-hydroxy-1,2,3,4-tetrahydro derivatives of quinoline in general. Thus, under the same conditions, 3-hydroxy-1,2,3,4-tetrahydro-5,6-benzoquinoline (V)

also gave approximately equal amounts of 5,6-benzoquinoline (VI) and 1,2,3,4-tetrahydro-5,6-benzoquinoline (VII).



The formation of a mixture of a quinaldine derivative and its 1,2,3,4-tetrahydro compound was noted previously when boiling together hydrochloric acid and the so-called aldol bases – compounds represented by the structure of 4-hydroxy-2-methyl-1,2,3,4-tetrahydroquinolines [3]. Consequently, both 3- and 4-hydroxy derivatives of 1,2,3,4-tetrahydroquinolines are capable of being converted into a mixture of the quinoline and its tetrahydro derivative. With the 3-hydroxy derivatives, considerably more drastic conditions are required than with the 4-hydroxy derivatives.

Somewhat unexpected results were obtained when 3-hydroxy-1,2,3,4-tetrahydro derivatives of benzoquinolines were treated with thionyl chloride. Thus, when (I) was heated with thionyl chloride for three hours on a boiling water bath, the reaction product isolated was a base with m.p. 100.7-101.0°, containing chlorine and with the composition of $C_{13}H_8NCl$. When treated with picric acid it gave a picrate with m.p. 243.2-243.7°. 6-Chloro-7,8-benzoquinoline (VIII) has the same composition and melting point and is obtained by heating 1-nitronaphthalene with glycerol and hydrochloric acid in a sealed tube [4]. We repeated the synthesis of the Polish investigators (whose data we can confirm completely) and established that mixed melting points of our compound with 6-chloro-7,8-benzoquinoline,



(VIII)

and also the corresponding picrates, were not depressed.

The yield of 6-chloro-7,8-benzoquinoline from the action of thionyl chloride on (I) was about 50%. It is noteworthy that substance (VIII) was isolated directly from the reaction mixture in quite a pure state – the melting point was only about 1-1.5° lower than that of the pure substance.

3-Hydroxy-1,2,3,4-tetrahydro-5,6-benzoquinoline (V) was treated with thionyl chloride under the same conditions to form 5,6-benzoquinoline (VI) in 65-68% yield.

We hope to examine the mechanism of the reaction between 3-hydroxy-1,2,3,4-tetrahydroquinoline derivatives and thionyl chloride in one of our next communications.

EXPERIMENTAL

Reaction of 3-hydroxy-1,2,3,4-tetrahydro-7,8-benzoquinoline (I) with hydrochloric acid. 1,2,3,4-Tetrahydro-7,8-benzoquinoline hydrochloride. Nine glass tubes were loaded with 1.0 g of 3-hydroxy-1,2,3,4-tetrahydro-7,8-benzoquinoline and 25 ml of concentrated hydrochloric acid (d.1.19) each. The sealed tubes were heated on an oil bath (bath temperature 190-195°) for eight hours. The contents of the tubes were made alkaline with 25% sodium hydroxide solution and extracted with ether (400 ml). The ether solution was dried with sodium carbonate and then saturated with hydrogen chloride. After two hours, the ether layer was poured off, the hydrochloride which had separated treated with 35 ml of 15% hydrochloric acid and the precipitate filtered off. Recrystallization from methyl alcohol (with charcoal purification) yielded 1.4 g (12.4%) of rhombic crystals of 1,2,3,4-tetrahydro-7,8-benzoquinoline hydrochloride. The m.p. was 262° (decomp.); according to [2], the m.p. is 260-261°.

Found %: C 71.2, 71.2; H 6.6, 6.5; N 6.1, 6.3; ionic chlorine 16.0, 16.1. $C_{13}H_{13}N \cdot HCl$. Calculated %: C 71.1; H 6.4; N 6.4; ionic chlorine 16.1.

1,2,3,4-Tetrahydro-7,8-benzoquinoline (IV). 0.6 g of (IV) hydrochloride was made alkaline with 6 ml of 10% sodium hydroxide and steam distilled. The precipitate in the distillate was filtered off. The weight was 0.3 g and the m.p. 44.1-44.8°. Recrystallization from petroleum ether (b.p. 45-65°) yielded colorless crystals of 1,2,3,4-tetrahydro-7,8-benzoquinoline with m.p. 45.4-45.9°. According to [2] the m.p. is 46.5°.

The picrate of 1,2,3,4-tetrahydro-7,8-benzoquinoline was prepared by mixing alcohol solutions of 0.10 g of (IV) and 0.13 g of picric acid (volume after mixing, 8 ml). The precipitate was collected. The yellow needles had m.p. 154.0-155.0° (from methyl alcohol).

Found %: N 13.5, 13.4. $C_{19}H_{16}O_7N_4$. Calculated %: N 13.6.

N-benzoyl-1,2,3,4-tetrahydro-7,8-benzoquinoline. The filtrate after separation of the precipitate of 1,2,3,4-tetrahydro-7,8-benzoquinoline hydrochloride (see above) and the residue, obtained by evaporating the mother liquors from recrystallization of this substance, were combined, made alkaline with 25% sodium hydroxide solution and extracted with ether (400 ml). The ether was distilled off, the residue (5.8 g) dissolved in 30 ml of ether and treated with 2.3 g of finely powdered potassium carbonate and 3.4 g of benzoyl chloride added dropwise over a period of 30 minutes, while the mixture was heated on a water bath (50-60°). After three hours heating, the reaction mixture was shaken with 25 ml of 10% sodium hydroxide. The precipitate was filtered off and washed with ether and water. The weight was 1.3 g; a further 0.4 g was isolated from the filtrate (ether layer) after extracting the 7,8-benzoquinoline from it with hydrochloric acid. The yield was 13% and the m.p. 188-189.5°. Recrystallization from methyl alcohol (with charcoal purification) yielded 1.3 g of colorless, crystalline needles of N-benzoyl-1,2,3,4-tetrahydro-7,8-benzoquinoline with m.p. 191.5-192.0°.

Found %: N 4.8, 4.9. $C_{20}H_{17}ON$. Calculated %: N 4.9.

A mixed melting point with a preparation, obtained analogously from authentic (IV), was not depressed.

7,8-Benzoquinoline (III). The filtrate after separation of the N-benzoyl-1,2,3,4-tetrahydro-7,8-benzoquinoline was poured into a separating funnel and 150 ml of 3.3% hydrochloric acid and 75 ml of ether added to it. After separation of the aqueous layer, the ether solution was repeatedly (three times) extracted with hydrochloric acid (until there was no longer turbidity when the acid solution was made alkaline). The combined hydrochloric acid solutions were made alkaline with 20% sodium hydroxide and extracted with ether. After removal of the ether, the 7,8-benzoquinoline was steam distilled. The weight was 3.5 g (44.4%) and the m.p. 49.7-50.3°. Recrystallization from petroleum ether gave colorless crystals of (III) with m.p. 50.5-51.0°. The literature reports 50.0° [5] and 52.0° [6].

Found %: C 87.2, 87.3; H 5.1, 5.0. $C_{13}H_9N$. Calculated %: C 87.1; H 5.1.

From substance (III) was prepared a hydrochloride with m.p. 214° (decomp.) and a picrate with m.p. 192.7-193.7°. The literature reports m.p. 213° [10] for the hydrochloride and 191.0-192.0° [6] for the picrate.

When the reaction was repeated with 9 g of (I) with hydrochloric acid under the same conditions, but isolating the whole of (IV) as the N-benzoyl derivative, the yield of this compound was 4.3 g (33%); 3.4 g (42%) of substance (III) was obtained.

The same yields were obtained when the reaction was performed with hydrochloric acid for 16 hours at 170-175°.

(III) was also obtained when (I) was reacted with hydriodic acid in the presence of acetic acid. Seven glass tubes were each loaded with 1.0 g of substance (I), 5 ml of acetic anhydride and 20 ml of concentrated hydriodic acid (d.1.55).

The tubes were heated on an oil bath at 200-210° for nine hours. The tubes were opened and the precipitate collected. The filtrate was made alkaline and extracted with ether to yield an insignificant amount of material, which was added to the precipitate and, after being made alkaline with 30% sodium hydroxide solution, steam distilled. The oily substance crystallized. The weight of (III) was 1.7 g and the m.p. 46.1-46.8°. Recrystallization from petroleum ether (b.p. 45-65°) gave a colorless product with m.p. 50-50.5°.

Reaction of 3-hydroxy-1,2,3,4-tetrahydro-5,6-benzoquinoline (V) with hydrochloric acid. N-Nitroso-1,2,3,4-tetrahydro-5,6-benzoquinoline. Two glass tubes, each containing 1.0 g of (V) and 25 ml of concentrated hydrochloric acid, were heated on an oil bath at 200-210° for nine hours. When the tubes had been opened, the contents were poured into a flask and made alkaline with 40% sodium hydroxide solution. The precipitate was collected, transferred to a flask, made alkaline with 3% sodium hydroxide and steam distilled. The oily substance crystallized. The weight was 1.0 g and the m.p. 90.5-91.5°. The crystalline substance was dissolved in 2% hydrochloric acid and sodium nitrite (as a 0.1 N solution) added to the solution until there was a reaction with starch-iodide paper. The N-nitroso-1,2,3,4-tetrahydro-5,6-benzoquinone was filtered off. The weight was 0.4 g and the m.p. 100.7-101.4°. Recrystallization from ether gave colorless plates with m.p. 104.8-105.1°. According to data in [7], the m.p. is 105.5°.

Found %: N 13.0, 13.2. $C_{13}H_{12}ON_2$. Calculated %: N 13.2.

5,6-Benzoquinoline (VI). The filtrate after separation of the N-nitroso-1,2,3,4-tetrahydro-5,6-benzoquinoline was made alkaline with 10% sodium hydroxide solution and the (VI) filtered off. The weight was 0.3 g and the m.p. 90.5-91.0°. According to data in [8], the m.p. is 93.5°.

Found %: C 87.0, 86.9; H 5.2, 5.1. $C_{13}H_9N$. Calculated %: C 87.1; H 5.1.

A picrate with m.p. 258.1-259.0° was also prepared. According to data in [9], the m.p. is 259°.

Reactions of (I) and (V) with thionyl chloride. 6-Chloro-7,8-benzoquinoline (VIII). 4.0 g of (I) and 20 ml of thionyl chloride were heated on a boiling water bath for three hours in a flask with a ground-glass jointed reflux condenser. When the reaction mixture had been cooled to room temperature, the precipitate was filtered off and dissolved in methyl alcohol and to the solution was added 25% sodium hydroxide in water until there was an alkaline reaction, and then 100 ml of water. Substance (VIII) was filtered off. The weight was 2.1 g and the m.p. 99.7-100.3°.

Recrystallization from methyl alcohol gave white needles of (VIII) with m.p. 100.7-101.0°. According to data in [4], the m.p. is 101°.

Found %: N 6.7, 6.6. $C_{13}H_8NCl$. Calculated %: N 6.6.

Hydrochloride of (VIII). 0.8 g of (VIII) was dissolved in 6 ml of methyl alcohol and the alcohol saturated with HCl. The hydrochloride of (VIII) was filtered off. The weight was 0.5 g and the m.p. 235° (decomp.). Recrystallization from methyl alcohol gave white needles of 6-chloro-7,8-benzoquinoline with m.p. 238° (decomp.).

Found %: N 5.7, 5.7; ionic chlorine 14.0, 14.1. $C_{13}H_8NCl \cdot HCl$. Calculated %: N 5.6; ionic chlorine 14.2.

A picrate of (VIII) with m.p. 243.5-244.0° was also prepared. According to data in [4], the m.p. is 240°.

Found %: C 51.6, 51.7; H 2.4, 2.3. $C_{19}H_{11}O_7N_4Cl$. Calculated %: C 51.5; H 2.6.

2.0 g of (V) and 8 ml of thionyl chloride were heated on a boiling water bath for 2.5 hours in a flask with a ground-glass jointed reflux condenser. The excess thionyl chloride was distilled off and the residue dissolved in 30 ml of methyl alcohol and heated for 15 minutes on a boiling water bath with activated charcoal. Then the hot filtrate was made alkaline with 10% sodium hydroxide in water and diluted with 100 ml of water. The 5,6-benzoquinoline, which precipitated over six hours, was collected. The weight was 1.2 g and the m.p. 85.1-86.5°.

Recrystallization from a mixture (15 : 1) of petroleum ether and methyl alcohol (using activated charcoal) gave white crystalline plates of (VI) with m.p. 90.2-90.7°.

SUMMARY

1. When 3-hydroxy-1,2,3,4-tetrahydrobenzoquinolines were heated with concentrated hydrochloric acid, mixtures of the corresponding benzoquinolines and tetrahydrobenzoquinolines were formed. The formation of these products may be explained by disproportionation of 1,2-(or 1,4-)dihydrobenzoquinolines, obtained as intermediates.

2. When 3-hydroxy-1,2,3,4-tetrahydro-7,8-benzoquinoline was treated with thionyl chloride, 6-chloro-7,8-benzoquinoline was obtained. When treated similarly, 3-hydroxy-1,2,3,4-tetrahydro-5,6-benzoquinoline gave 5,6-benzoquinoline. In the action of thionyl chloride on these compounds there occurred dehydration and dehydrogenation and in the case of 3-hydroxy-1,2,3,4-tetrahydro-7,8-benzoquinoline, chlorination of the aromatic nucleus as well.

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THE PROCESS OF POLYAMIDE RESIN FORMATION

VII. THE COMPOSITION AND STRUCTURE OF SALTS FORMED BY DICARBOXYLIC ACIDS AND DIAMINES OR HYDRAZINE

A.S. Shpital'nyi and Ia.A. Kharit

In work published previously [1], it was established that although the salts of dicarboxylic acids and aliphatic diamines could be either acidic or neutral, their composition was constant and did not depend on the ratio of the reacting components. The composition of the salt was determined by the relation of the dissociation constants of the acid. When the ratio had low values, neutral salts were formed and at high values, acid salts. These conclusions were arrived at as a result of studying the salts of adipic, succinic and oxalic acids.

In the present work the number of acids used for preparing the salts which interested us was increased to include azelaic and sebacic acids.

There are no diamines in the aliphatic series which possess strongly differing dissociation constants, as is observed among the acids [1]. To elucidate the effect on the salt composition of a high value of the ratio K_1/K_2 for the basic component, we used the dicarboxylic acid salts of hydrazine, which is known to have a very considerable value for K_1/K_2.

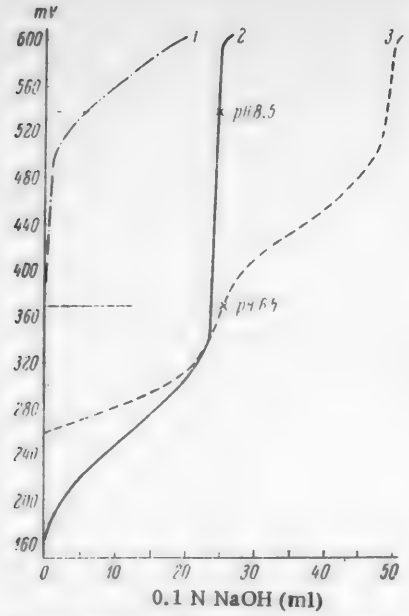
As previously [1], hexamethylenediamine and ethylenediamine were used as bases for salt formation. The preliminarily dissolved starting reagents were mixed, not only in equimolecular proportions, but also with a considerable excess of one or another of them. In only one case, actually in the preparation of a salt from hexamethylenediamine and excess sebacic acid, did we have to limit the excess of the acid due to difficulties in purifying the salt. In the rest of the experiments, no such limitations were required. A salt was also prepared from hexamethylenediamine and excess adipic acid, as the salt from these components, in the ratio of 1:2, was not examined in the previous work. K_1 and K_2 of azelaic and sebacic acids differ very insignificantly (Table 1).

TABLE 1

Name of acid	Dissociation constants
Sebacic	$K_1 = 2.34 \cdot 10^{-5}$ [2] $K_2 = 2.80 \cdot 10^{-5}$ [3] $K_2 = 2.55 \cdot 10^{-6}$ [4]
Azelaic	$K_1 = 2.88 \cdot 10^{-5}$ [5] $K_2 = 2.80 \cdot 10^{-6}$ [5]

Note: Temperature 25°.

Therefore, in accordance with the proposition above, one would expect that these acids would form salts of constant composition with diamines and the components of these would be present in equimolecular proportions. Judging by the data in Table 2, one would expect that neutral salts would crystallize at any ratio of the components. It was suggested that these salts should be represented as rings [1]



Titration curves: 1) 0.05 M solution of 66 salt (hexamethylenediamine + adipic acid) (25 ml); 2) 0.025 M solution of adipic acid (50 ml); 3) 0.025 M solution of salt, obtained from hydrazine and adipic acid (50 ml).

$$^{-}OOCRCOO^{-}$$
$$^{+}H_3NR_1NH_3^{+}.$$

This type of representation has found support in handbooks on synthetic fibers with [6] and without [7] references to our work.

Apart from the considerations presented [1], evidence in favor of the cyclic structure is provided by a number of factors, for example, the capacity of related salts of ϵ-aminocaproic acid to form considerable amounts of rings (lactam) when distilled [8] or the presence in glycine crystals of hydrogen bonds between molecules lying in adjacent layers and not only in a linear direction [9], etc.

In contrast to diamines, the dissociation constants of hydrazine differ sharply from each other: at 25°, $K_1 = 8.5 \cdot 10^{-7}$ and $K_2 \approx 10^{-16}$ [10]. Due to the low value of the second dissociation constant, it is considered [11] that hydrazine is practically a monoacidic base and is more similar to ammonia and amines than to diamines. Although with dibasic mineral acids it is able to form salts of the type

$$(N_2H_4)_2H_2B,\ N_2H_4H_2B \text{ and } N_2H_4 2H_2B.$$

(H_2B is a dibasic acid), $N_2H_6^{++}$ ions do not exist in aqueous solution as they immediately react with water and are converted to $N_2H_5^{+}$. Therefore, a solution of hydrazine dihydrochloride is the same as a solution containing equimolecular amounts of free hydrogen chloride and hydrazine monochloride [11]. Raman spectra of crystals of divalent hydrazine show bands corresponding not only to divalent, but also to monovalent hydrazine ions ($N_2H_5^{+}$) [12].

According to our information, the description of salts of hydrazine and saturated dicarboxylic acids in the literature is limited to salts of oxalic [13] and succinic acids [14].

Since the aim of our investigations was to elucidate the effect of different ratios of starting components on the composition of the salt, we isolated a series of salts of hydrazine and dicarboxylic acids by the methods indicated above, including the salts that had been prepared previously.

From the data presented in Table 3, it follows that with molar ratios of hydrazine and dicarboxylic acid of 1:1 and 1:2, salts of constant composition are obtained with a component ratio of 1:1. With excess hydrazine (a ratio of 2:1), the composition of the salts with a component ratio of 1:1 is maintained for salts of sebacic and azelaic acids. For salts of adipic and succinic acids, in this case the component ratio is 2 moles of hydrazine to 1 mole of acid. They were isolated from an alcohol solution as an oil, which slowly crystallized after heating in vacuum to form crystals that deliquesced in air.

Thus, in contrast to diamines, hydrazine forms salts of constant composition with only some dicarboxylic acids. There are dicarboxylic acids with which hydrazine forms salts of two types: $N_2H_4H_2B$ and $(N_2H_4)_2H_2B$.

It was indicated above that hydrazine can form diacidic salts with mineral acids. It was interesting to determine whether organic salts of hydrazine of the type $N_2H_4H_2B$ also had the properties of the diacidic mineral salts. With this aim, the behavior of the salts in aqueous solution was examined. It was established that crystals of the organic acid were deposited from concentrated aqueous solutions and in potentiometric titration of dilute aqueous solutions of it, 1 mole of the organic acid was titrated with alkali with satisfactory accuracy, as shown by the titration curve of a solution of salt obtained from hydrazine and adipic acid (see the figure). For comparison, the titration curves of 66 salt (hexamethylenediamine + adipic acid) and adipic acid are given.

Consequently, in aqueous solutions the given salts behave as compounds with the formula

TABLE 2

Composition and Structure of Salts Formed by Diamines and Dicarboxylic Acids*

Salt components	Molar ratio diamine and acid	Yield (в %)	Melting point	Found (%)			Empirical formula	Calculated (%)			Formula
				C	H	N		C	H	N	
Hexamethylenediamine Sebacic acid	1 : 1	94	172—173°	60.25	10.22	8.42	$C_{16}H_{34}O_4N_2$	60.37	10.69	8.80	$^+H_3N(CH_2)_6NH_3^+$ $-OOC(CH_2)_8COO^-$
Hexamethylenediamine Sebacic acid	2 : 1	92	173	59.95	10.32	8.48	$C_{16}H_{34}O_4N_2$	60.37	10.69	8.80	
Hexamethylenediamine Sebacic acid	1 : 1.5	60	172	60.33	10.44	8.52	$C_{16}H_{34}O_4N_2$	60.37	10.69	8.80	
Hexamethylenediamine Adipic acid	1 : 2	90	191—192	54.62	9.81	10.42	$C_{12}H_{26}O_4N_2$	54.96	9.92	10.68	$^+H_3N(CH_2)_6NH_3^+$ $-OOC(CH_2)_4COO^-$
Hexamethylenediamine Azelaic acid	1 : 1	65	146	59.32	10.43	9.12	$C_{15}H_{32}O_4N_2$	59.21	10.52	9.21	$^+H_3N(CH_2)_6NH_3^+$ $-OOC(CH_2)_7COO^-$
Hexamethylenediamine Azelaic acid	2 : 1	68	146—147	59.11	10.63	9.58	$C_{15}H_{32}O_4N_2$	59.21	10.52	9.21	
Hexamethylenediamine Azelaic acid	1 : 2	84	146—147	59.26	10.25	9.18	$C_{15}H_{32}O_4N_2$	59.21	10.52	9.21	
Ethylenediamine Sebacic acid	1 : 1	91	162—163	55.28	10.12	10.52	$C_{12}H_{26}O_4N_2$	54.97	9.92	10.68	$^+H_3N(CH_2)_2NH_3^+$ $-OOC(CH_2)_8COO^-$
Ethylenediamine Sebacic acid	2 : 1	91	161—162	55.36	10.19	10.80	$C_{12}H_{26}O_4N_2$	54.97	9.92	10.68	
Ethylenediamine Sebacic acid	1 : 2	90	161—162	55.46	10.07	10.55	$C_{12}H_{26}O_4N_2$	54.97	9.92	10.68	
Ethylenediamine Azelaic acid	1 : 1	97	145	53.47	9.82	10.89	$C_{11}H_{24}O_4N_2$	53.22	9.67	11.29	$^+H_3N(CH_2)_2NH_3^+$ $-OOC(CH_2)_7COO^-$
Ethylenediamine Azelaic acid	2 : 1	97	145	53.60	9.98	11.17	$C_{11}H_{24}O_4N_2$	53.22	9.67	11.29	
Ethylenediamine Azelaic acid	1 : 2	80	145—147	53.60	9.98	10.79	$C_{11}H_{24}O_4N_2$	53.22	9.67	11.29	

*Data obtained with the help of B.I. Khubavii.

TABLE 3

Composition and Structure of Salts Formed by Hydrazine and Dicarboxylic Acids*

Salt components	Molar ratio of hydrazine and acid	Yield (%)	Melting point	N_2H_4 found (in %)	Empirical formula	N_2H_4 calc. (%)	Formula
Hydrazine Sebacic acid	1 : 1	92	103—104°	13.25	$C_{20}H_{44}O_8N_4$	13.67	$N_2H_5^+{}^-OOC(CH_2)_8COO^-{}^+H_5N_2 \cdot HOOC(CH_2)_8COOH$
Hydrazine Sebacic acid	1 : 2	85	103—104	13.46	$C_{20}H_{44}O_8N_4$	13.67	
Hydrazine Sebacic acid	2 : 1	80	102—103	13.35	$C_{20}H_{44}O_8N_4$	13.67	
Hydrazine Azelaic acid	1 : 1	88	88	14.44	$C_{18}H_{40}O_8N_4$	14.54	$N_2H_5^+{}^-OOC(CH_2)_7COO^-{}^+H_5N_2 \cdot HOOC(CH_2)_7COOH$
Hydrazine Azelaic acid	1 : 2	85	87—89	14.38	$C_{18}H_{40}O_8N_4$	14.54	
Hydrazine Azelaic acid	2 : 1	55	88—89	14.62	$C_{18}H_{40}O_8N_4$	14.54	
Hydrazine Adipic acid	1 : 1	85	114	17.85	$C_{16}H_{28}O_8N_4$	17.98	$N_2H_5^+{}^-OOC(CH_2)_4COO^-{}^+H_5N_2 \cdot HOOC(CH_2)_4COOH$
Hydrazine Adipic acid	1 : 2	83	113—115	17.65	$C_{16}H_{28}O_8N_4$	17.98	
Hydrazine Adipic acid	2 : 1	72	Oil and hygroscopic crystals	30.95	$C_8H_{18}O_4N_4$	30.47	$N_2H_5^+{}^-OOC(CH_2)_4COO^- \cdot {}^+H_5N_2$
Hydrazine Succinic acid	1 : 1	62	120	20.92	$C_8H_{20}O_8N_4$	21.33	$N_2H_5^+{}^-OOC(CH_2)_2COO^-{}^+H_5N_2 \cdot HOOC(CH_2)_2COOH$
Hydrazine Succinic acid	1 : 2	54	120—121	20.83	$C_8H_{20}O_8N_4$	21.33	
Hydrazine Succinic acid	2 : 1	52	Oil and hygroscopic crystals	34.82	$C_4H_{12}O_4N_4$	35.16	$N_2H_5^+{}^-OOC(CH_2)_2COO^-{}^+H_5N_2$

*Data obtained with the help of T.G. Antonova and Chang Shih-yü.

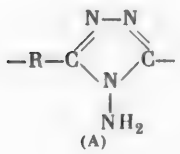
$N_2H_5^+{}^-OOCRCOO^-{}^+H_5N_2HOOCRCOOH$,

i.e., as acid salts and in this respect they were similar to salts of hydrazine with mineral acids.

These data indicate that in the salts in which the acidic component is a dicarboxylic acid, the hydrazine is a monoacidic base at all component ratios, including the ratio 1:1.

The acid salts readily crystallized from alcohol solutions in contrast to the neutral ones, which separated as an oil that slowly formed hygroscopic crystals.

From the material presented it follows that hydrazine and diamines behave differently in the formation of salts with dicarboxylic acids. The same difference is also noted in the formation of polyamide resins from these compounds. While from different ratios of the dicarboxylic acids and diamines, one can expect only changes in the length of the polymer macromolecules and not changes in the composition, which is characterized by the regular alternation of one acid residue and one diamine residue $-HN-R-NH-CO-R_1-CO-$; in the case of the polycondensation of hydrazine with dicarboxylic acids we observe the formation of a polymer with a structural group consisting of one acid residue and two hydrazine residues (A) [15].



(A)

Thus, hydrazine behaves as a monacidic base in the formation of polyamide resins, also. This leads to the conclusion that not only the compositions of the salts from which the polyamides are formed, but also the compositions of the polyamide polymers are regulated by the ratio of the dissociation constants of the functional groups of the components.

EXPERIMENTAL

Salts were prepared from sebacic and azelaic acids and diamines by the method described in [1].

98% hydrazine was used for the preparation of salts from dicarboxylic acids and hydrazine. Since salts based on hydrazine crystallized slowly and in poor yields from aqueous alcohol solutions, they were obtained from 96% alcohol.

When salts were prepared from hydrazine and adipic and succinic acids in a molar ratio of 2:1, an oil precipitated. The oil was separated from the alcohol and heated in vacuum (5-10 mm) on a boiling water bath for one hour to remove traces of alcohol and water. The oil crystallized on standing.

The amount of hydrazine in the salts was determined directly by the iodate method, using a solvent [16].

SUMMARY

1. It was established that the composition of salts of diamines and azelaic and sebacic acids, prepared with various molar ratios of the starting reagents, was constant and this agrees with previous conclusions [1] on salts of a series of other dicarboxylic acids.

2. With sebacic and azelaic acids, hydrazine forms salts which contain equimolecular amounts of the base and the acid. Adipic and succinic acids form such salts only in the absence of excess hydrazine. In the latter case, the presence of excess hydrazine causes the formation of salts with the composition of 2 moles of hydrazine to 1 mole of acid.

3. It was established that hydrazine behaves as a monoacidic base in aqueous solutions of salts composed of hydrazine and a dicarboxylic acid in equimolecular amounts.

4. The composition of polyamide resins, formed from dicarboxylic acids and diamines or hydrazine, apparently, similarly to the composition of the salts of the corresponding compounds, is controlled by the values of the dissociation constants of the starting materials.

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INVESTIGATION OF HETEROCYCLIC N–OXIDES

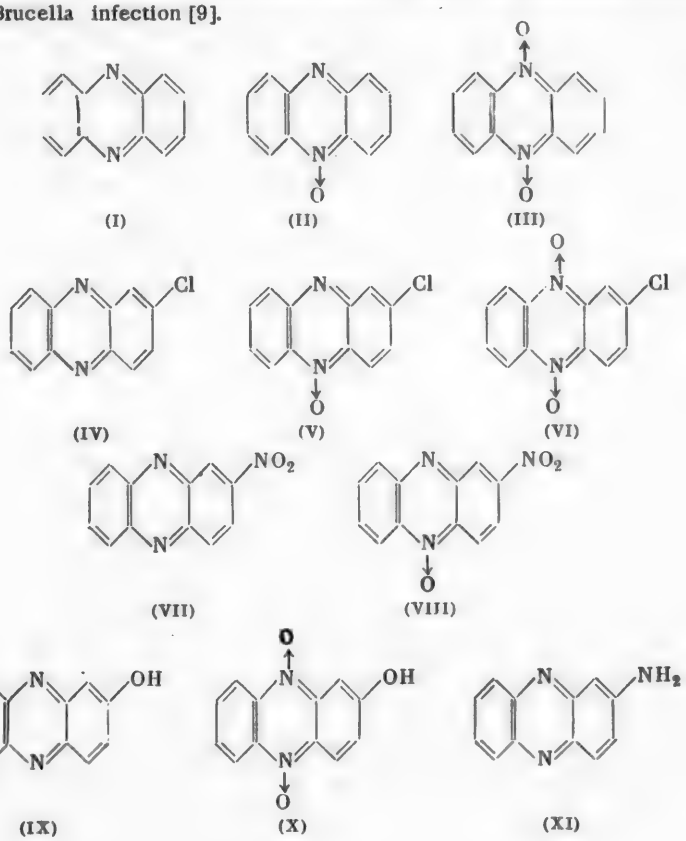
VI. POLAROGRAPHIC REDUCTION OF SOME N–OXIDES OF PHENAZINES AND ACRIDINES

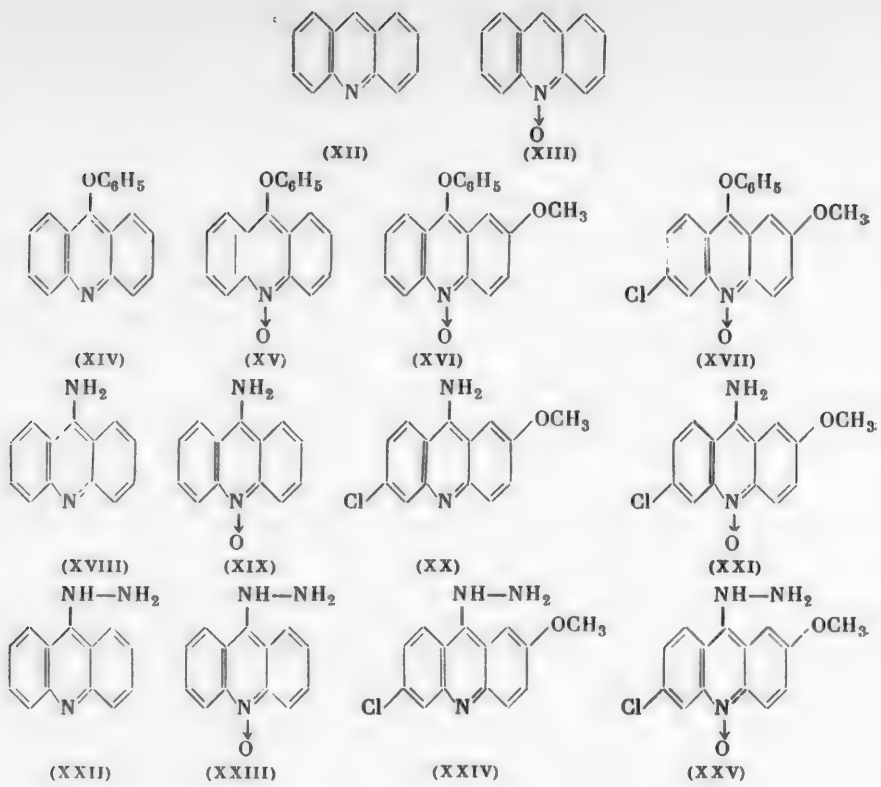
O.N. Nechaeva and Z.V. Pushkareva

N-Oxides of nitrogen-containing heterocyclic compounds are interesting in many connections and, in particular, some of them are of interest as physiologically active substances [1-3]. The N-oxides of the pyridine and quinoline series have been studied in most detail [4].

In our previous reports we described the results of the synthesis and systematic study of N-oxides of more complex heterocyclic systems (acridine, quinoxaline, phenazine and others) [5-8]. One of us and L.V. Variukhina [7] were able to use the polarographic method to establish the relation between the structure of the molecule and the ease of reduction of the N → O bond.

In developing these investigations, we examined the polarographic reduction of compounds (IV)-(XI) of the phenazine series and (XIV)-(XXV) of the acridine series, some of which were synthesized for testing their action on the organism causing Brucella infection [9].





The phenazine derivatives were synthesized so as to follow the effect of different substituents on the stability of the N → O bond relative to reduction at a dropping mercury electrode and on the capacity for reduction of the heterocyclic system itself. A study was made in parallel of the effect of substituents on the biological activity of the N-oxide (II) and dioxide of phenazine (III), of which the latter is more active than "acrichin" (atebrin) as regards the organism causing Brucella infection. The substituents chosen were Cl, NH_2, OH and the electron acceptor group NO_2. All the substituents were introduced into the β-position of the phenazine ring.

In the acridine series, we studied some compounds which we were the first to prepare [9] – N-oxides of 9-amino and 9-hydrazino derivatives, (XIX), (XXI), (XXIII), (XXV), and also N-oxides of 9-phenoxy derivatives (XV)-(XVII), which are intermediates in the preparation of 9-amino and 9-hydrazino derivatives and are of interest in themselves to some extent.

Both in the phenazine and the acridine series, we also studied the unoxidized base, corresponding to each of the N-oxides.

Substances (IV)-(XI), and also (XIV), (XVII), (XVIII), (XX), (XXII) were synthesized by methods described in the literature; the syntheses of substances (XV), (XVI), (XIX), (XXI), and (XXIII)-(XXV) were described in a previous communication [9]. All substances were carefully purified by recrystallization to constant melting point.

The polarographic reduction was performed in a Heyrovsky micropolarograph with which the curves of current strength against voltage were obtained automatically and recorded photographically. The measurements for the acridine derivatives were performed with a galvanometer sensitivity of 1/30 and 1/50 and for the phenazine derivatives, a sensitivity of 1/100. The bulk of the compounds were polarographed at a concentration of $1 \cdot 10^{-3}$ M. The exceptions were 2-hydroxyphenazine and the dioxide of 2-hydroxyphenazine, which were reduced at $1 \cdot 10^{-4}$ M concentration due to their low solubility. All the measurements were performed in alcohol solution in an acetate buffer.

The polarographic curves are shown in Figs. 1-20. The measurement results are given in Table 1. All the half-wave potential values ($E_{1/2}$) are relative to the potential of a saturated calomel electrode (s.c.e.).

TABLE 1

Formula No. in text	Name of substance	Melting point	Concentration (M)	Half-wave potential (relative to a saturated calomel electrode) (V)	Limiting diffusion current (mA)
(I)	Phenazine	171°	$1 \cdot 10^{-3}$	—0.364	5.00
(II)	Phenazine N-oxide	224	$1 \cdot 10^{-3}$	—0.218, —0.382	3.50, 3.10
(III)	Phenazine dioxide	190—191	$1 \cdot 10^{-3}$	—0.218, —0.364	7.77, 4.04
(IV)	2-Chlorophenazine	139	$1 \cdot 10^{-3}$	—0.42	5.70
(V)	2-Chlorophenazine N-oxide	174—175	$1 \cdot 10^{-3}$	—0.22, —0.42	5.75, 5.72
(VI)	2-Chlorophenazine dioxide	190—191	$1 \cdot 10^{-3}$	—0.27, —0.47	12.50, 6.25
(VII)	2-Nitrophenazine	217	$1 \cdot 10^{-3}$	—0.25, —0.69	3.64, 15.10
(VIII)	2-Nitrophenazine N-oxide	203	$1 \cdot 10^{-3}$	—0.24, —0.72	9.90, 15.20
(IX)	2-Hydroxyphenazine	254	$1 \cdot 10^{-4}$	—0.45	0.57
(X)	2- " " dioxide	280	$1 \cdot 10^{-4}$	—0.30, —0.45	3.11, 1.56
(XI)	2-Aminophenazine	287	$1 \cdot 10^{-3}$	—0.54	6.50
(XII)	Acridine	107	$1 \cdot 10^{-3}$	—0.618	2.08
(XIII)	Acridine N-oxide	169 (decomp)	$1 \cdot 10^{-3}$	—0.854	4.66
(XIV)	9-Phenoxyacridine	131	$1 \cdot 10^{-3}$	—0.74, —1.57	3.64, 6.50
(XV)	9-Phenoxyacridine N-oxide	152	$1 \cdot 10^{-3}$	—0.82, —1.60	2.85, 2.90
(XVI)	2-Methoxy-9-phenoxy-acridine N-oxide	138	$1 \cdot 10^{-3}$	—0.81, —1.50	5.70, 4.41
(XVII)	2-Methoxy-6-chloro-9-phenoxyacridine N-oxide	175	$1 \cdot 10^{-3}$	—0.80, —1.54	3.12, 1.88
(XVIII)	9-Aminoacridine	236	$1 \cdot 10^{-3}$	—1.21, —1.51	4.80, 0.91
(XIX)	9-Aminoacridine N-oxide	223	$1 \cdot 10^{-3}$	—0.98, —1.24, —1.54	2.89, 3.38, 0.92
(XX)	2-Methoxy-6-chloro-9-aminoacridine	250	$1 \cdot 10^{-3}$	—1.20, —1.50	4.58, 0.91
(XXI)	2-Methoxy-6-chloro-9-aminoacridine N-oxide	237	$1 \cdot 10^{-3}$	—0.98, —1.25, —1.51	3.65, 4.68, 1.30
(XXII)	9-Hydrazinoacridine	169	$1 \cdot 10^{-3}$	—0.96, —1.30	2.87, 4.75
(XXIII)	9-Hydrazinoacridine N-oxide	168	$1 \cdot 10^{-3}$	—0.98, —1.24	2.87, 3.90
(XXIV)	2-Methoxy-6-chloro-9-hydrazinoacridine	161	$1 \cdot 10^{-3}$	—0.70, —1.27	1.17, 3.98
(XXV)	2-Methoxy-6-chloro-9-hydrazinoacridine N-oxide	171	$1 \cdot 10^{-3}$	—0.66, —1.44	2.85, 3.90

Phenazine Derivatives

As is known, phenazine is a heterocycle which readily undergoes oxidation-reduction conversions. It is readily reduced at a mercury dropping electrode at $E_{1/2} = -0.364$ V. According to data in [7], the N → O bond in phenazine N-oxide is reduced at a mercury dropping electrode more readily than in the N-oxides of other heterocycles, giving a half-wave potential, which is strongly displaced toward positive values (−0.22 V).

The reduction of phenazine N-oxides, which do not contain readily reducible groups as substituents, proceeds in two stages, giving a polarographic curve with two waves (Figs. 2, 3 and 7). Here the first wave refers to the reduction of the N → O bond and the second to the reduction of the phenazine system to the dihydrophenazine. With a nitro group present in the molecule, one would expect the appearance of three waves, though the polarographic curve (Fig. 5) has only two waves. This is apparently due to the fact that in this molecule the N → O bond and the phenazine system are reduced at identical half-wave potential values (−0.24 V). In fact, the height of the first wave in the case of the N-oxide is almost twice as great as the first wave for the unoxidized base (Figs. 4 and 5).

The unoxidized bases give polarographic curves with one wave (Figs. 1, 6 and 8). The exception is 2-nitrophenazine and the second wave on its polarogram corresponds to the reduction of the nitro group (Fig. 4).

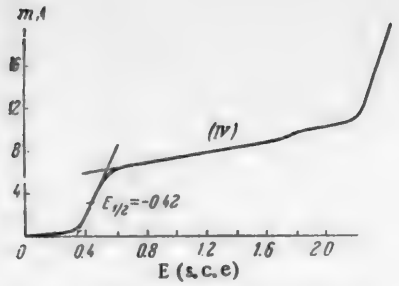


Fig. 1. Polarogram of 2-chlorophenazine.

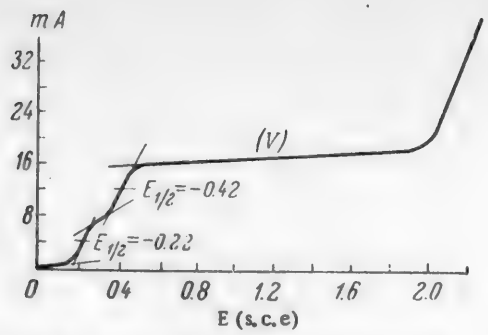


Fig. 2. Polarogram of 2-chlorophenazine N-oxide.

Data presented in Table 1 show that the reduction potential of the N → O bond changes, depending on the character of the substituent in the phenazine N-oxide ring. The introduction of chlorine into position 2 of phenazine N-oxide has hardly any effect on the capacity of the N → O bond for reduction at a mercury dropping electrode. Thus, the half-wave potential of 2-chlorophenazine N-oxide is −0.22 V, for 2-chlorophenazine dioxide it is −0.27 V and −0.22 V for unsubstituted phenazine N-oxides (Figs. 2 and 3). The introduction of a nitro group into the same position gives approximately the same effect. The results are changed when the substituents are the electron donor groups OH and NH_2, which produce a displacement of the half-wave potential toward more negative values.

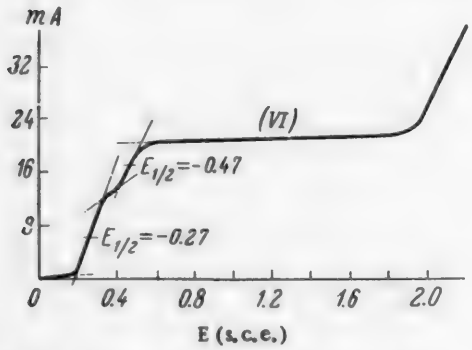


Fig. 3. Polarogram of 2-chlorophenazine dioxide.

A similar picture was also observed on analyzing the half-wave potentials referring to the phenazine molecules themselves (Table 2) (the second wave in the case of the N-oxides and the first wave in the case of the unoxidized bases).

As can be seen, conjugation of an electron-donor group with the ring leads to a considerable increase in the electron density at the hetero atom, making its reduction at a mercury dropping electrode more difficult. On the other hand, the electron-acceptor nitro group facilitates the reduction.

In the synthesis of N-oxides for biological testing, there is interest in the general result: by introducing substituents into the phenazine ring it is possible to affect the stability of the N → O bond with respect to reduction (it is known that some N-oxides, which have biological activity in vitro, are easily inactivated in vivo due to the loss of the oxide oxygen .

TABLE 2

Substance	Phenazine	2-Chloro-phenazine	2-Nitro-phenazine	2-Hydroxy-phenazine	2-Amino phenazine
$E_{1/2}$ (V)	−0.36	−0.37	−0.20	−0.45	−0.54

Acridine Derivatives

By comparing polarograms for 9-chloroacridine N-oxide and unoxidized 9-chloroacridine derivatives, it was shown [7] that in contrast to acridine N-oxide (XIII), they gave two polarographic waves and the second of these was due to the chemical features of the heterocycle itself.

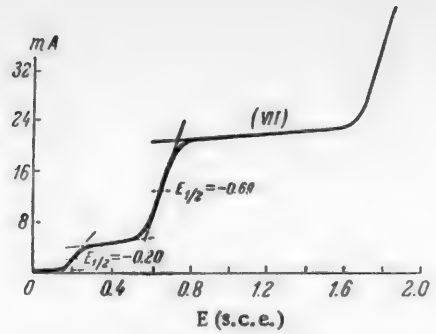


Fig. 4. Polarogram of 2-nitrophenazine.

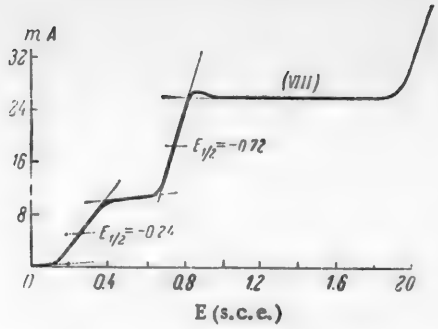


Fig. 5. Polarogram of 2-nitrophenazine N-oxide.

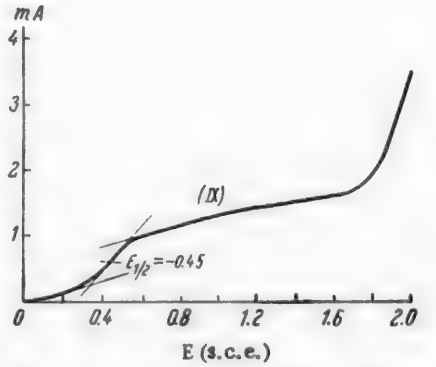


Fig. 6. Polarogram of 2-hydroxyphenazine.

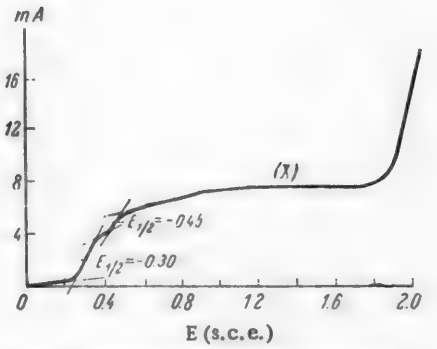


Fig. 7. Polarogram of 2-hydroxyphenazine dioxide.

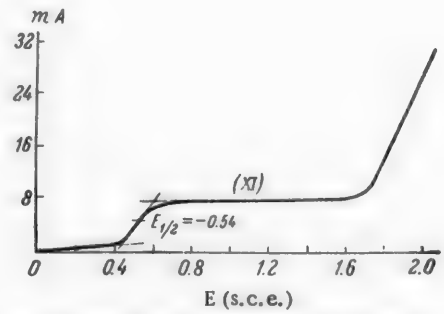


Fig. 8. Polarogram of 2-aminophenazine.

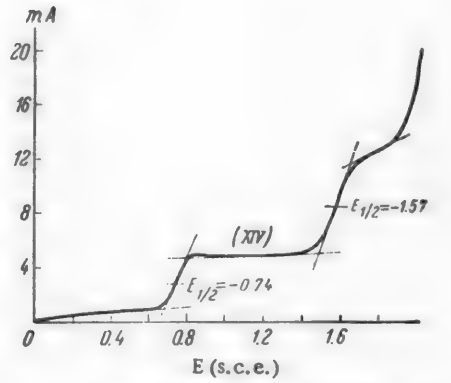


Fig. 9. Polarogram of 9-phenoxyacridine.

By considering the data on polarographic reduction, presented in Table 1, one can make the following observations.

1. Like 9-chloroacridine and in contrast to unsubstituted acridine, 9-phenoxyacridine (XIV) gives two polarographic waves. The value of $E_{1/2}$ for the first wave is close to the half-wave potential of acridine (−0.75 and −0.62 V, respectively), while the second stage of the reduction proceeds at strongly negative half-wave potentials (−1.58 V), giving a definite wave on the polarogram (Fig. 9).

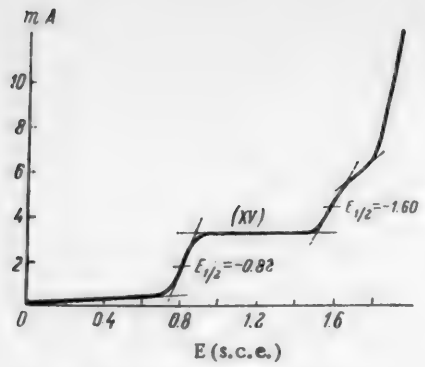


Fig. 10. Polarogram of 9-phenoxyacridine N-oxide.

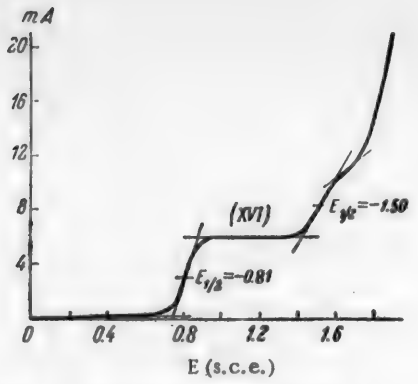


Fig. 11. Polarogram of 2-methoxy-9-phenoxyacridine N-oxide.

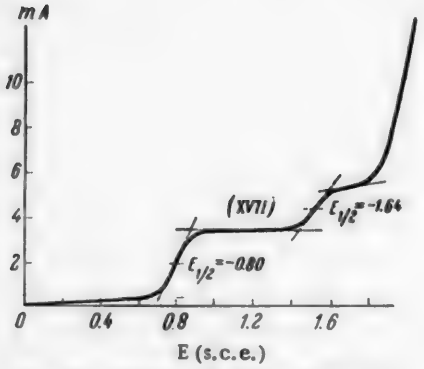


Fig. 12. Polarogram of 2-methoxy-6-chloro-9-phenoxyacridine N-oxide.

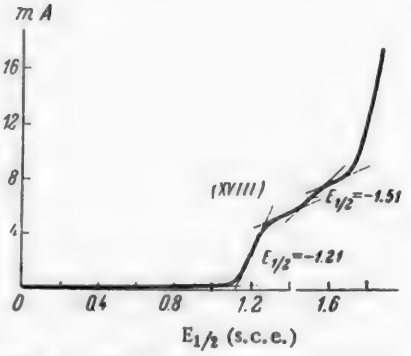


Fig. 13. Polarogram of 9-aminoacridine.

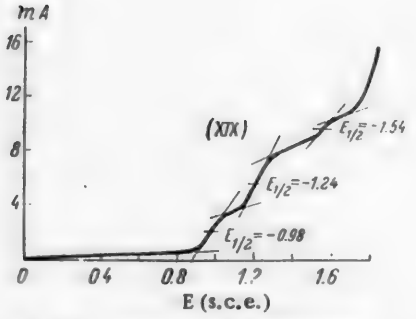


Fig. 14. Polarogram of 9-aminoacridine N-oxide.

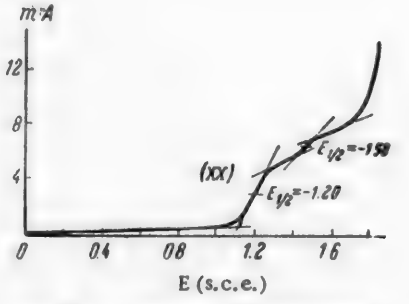


Fig. 15. Polarogram of 2-methoxy-6-chloro-9-aminoacridine.

Unexpectedly, 9-phenoxyacridine N-oxides also give two,and not three,waves, when the $E_{1/2}$ value of the second wave remains almost unchanged (of the order of −1.5 to −1.6 V) and the first stage of the reduction proceeds at a potential of from −0.80 to −0.82 V, i.e., with approximately the same ease as the reduction of the N → O bond in unsubstituted acridine N-oxide (−0.85 V) (Figs. 10-12). It is still unclear why the wave characterizing the reduction of the acridine ring is absent from the polarogram.

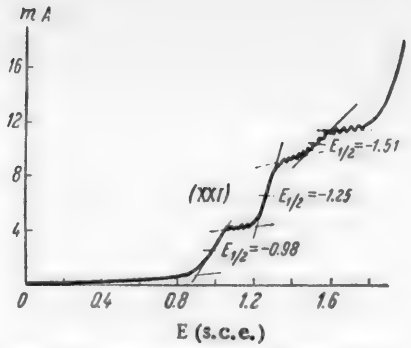


Fig. 16. Polarogram of 2-methoxy-6-chloro-9-aminoacridine N-oxide.

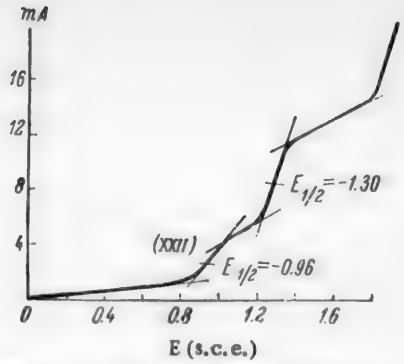


Fig. 17. Polarogram of 9-hydrazinoacridine.

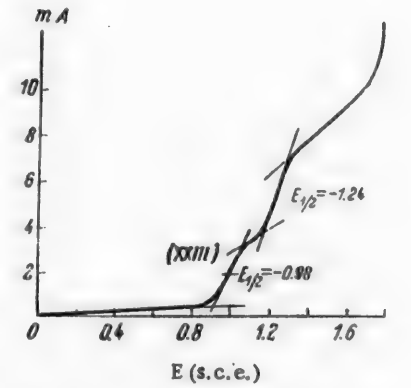


Fig. 18. Polarogram of 9-hydrazinoacridine N oxide.

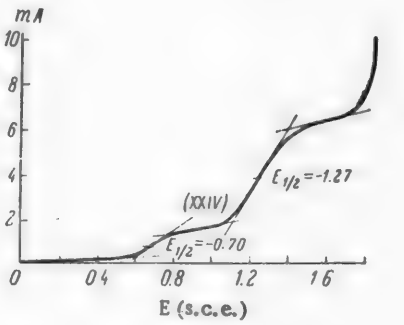


Fig. 19. Polarogram of 2-methoxy-6-chloro-9-hydrazinoacridine.

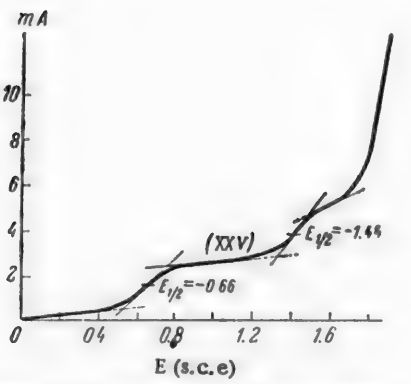


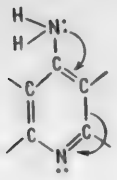
Fig. 20. Polarogram of 2-methoxy-6-chloro-9-hydrazinoacridine N-oxide.

2. 2-Aminoacridine (XVIII) and 2-methoxy-6-chloro-9-aminoacridine (XX) are reduced at half-wave potentials, which are strongly displaced toward more negative values (−1.21 and −1.20 V instead of −0.618 V for acridine), apparently as a result of conjugation in the system (XXVI) and a considerable increase in the electron density at the hetero atom. In addition, the polarograms show a second indistinct wave with $E_{1/2}$ = −1.51 and −1.50 V (Figs. 13 and 15).

The 9-aminoacridine N-oxides (XIX) and (XXI) are reduced in two stages (there is also an indistinct third wave at strongly negative potentials). The first stage corresponds to the reduction of the N → O bond (−0.98 V) and the second to the reduction of the acridine ring (−1.24 and −1.25 V) (Figs. 14 and 16).

3. The reduction of 9-hydrazinoacridines (XXII) and (XXIV) goes in two stages and the polarograms show two quite distinct waves (Figs. 17 and 19).

In all probability, the first half-wave potential refers to the reduction of the hydrazine link (considering data on the polarographic reduction of arylhydrazines). On going from the unoxidized bases to the N-oxides, as



(XXVI)

in the case of the 9-phenoxy derivatives, the polarograms show only two reduction stages (Figs. 18 and 20).

As in the phenazine series, in general the introduction of electron-donor groups (amino and hydrazino groups) into position 9 of the acridine N-oxide molecule leads to considerable stability of the N → O bond toward reduction at a mercury dropping electrode.

SUMMARY

The polarographic reduction of 20 heterocyclic compounds was performed. It was shown that the introduction of substituents of different characters into the acridine and phenazine N-oxide molecules substantially affects the half-wave potential of the N → O bond and the heterocycle itself; here an electron-acceptor group (NO_2) produces a displacement of the half-wave potentials toward more positive values; on the other hand, electron-donor groups (NH_2 and OH) displace the half-wave potentials toward more negative values.

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INVESTIGATION OF HETEROCYCLIC N–OXIDES

VII. DIPOLE MOMENTS AND CHEMICAL FEATURES OF SOME DERIVATIVES OF PHENAZINE AND ACRIDINE N–OXIDES

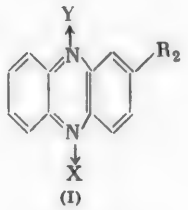
Z. V. Pushkareva and O. N. Nechaeva

In one of our previous communications, we described the results of measuring the dipole moments of the N-oxides of various heterocyclic systems and demonstrated the dependence of the dipole moment of the N → O bond on the structure of the heterocycle and the interrelation of the polarity of the N → O bond and its capacity for reduction at a mercury dropping electrode [1].

We synthesized a series of N-oxides of phenazine (I) and acridine (VIII), containing various substituents in the ring, for testing their action on the organism causing Brucella infection [2] and to reduce them polarographically [3].

The dipole moments of a considerable number of these N-oxides and the unoxidized bases corresponding to them were studied and the present article is devoted to the results of these measurements [for the phenazine derivatives (II)-(VII) and the acridine derivatives (IX)-(XVI)].

Substances (II)-(VII), (IX), (XII) and (XIII) were synthesized by methods described in the literature. We prepared and described [2] substances (X), (XI), (XIV)-(XVI) previously. All the substances were carefully purified to constant melting point.



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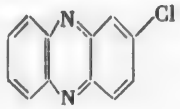

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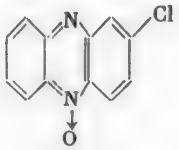

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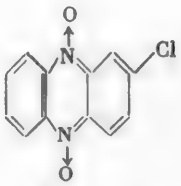

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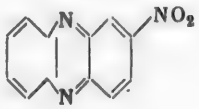

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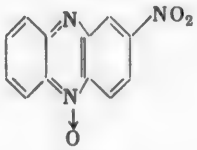

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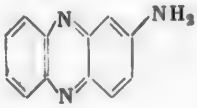

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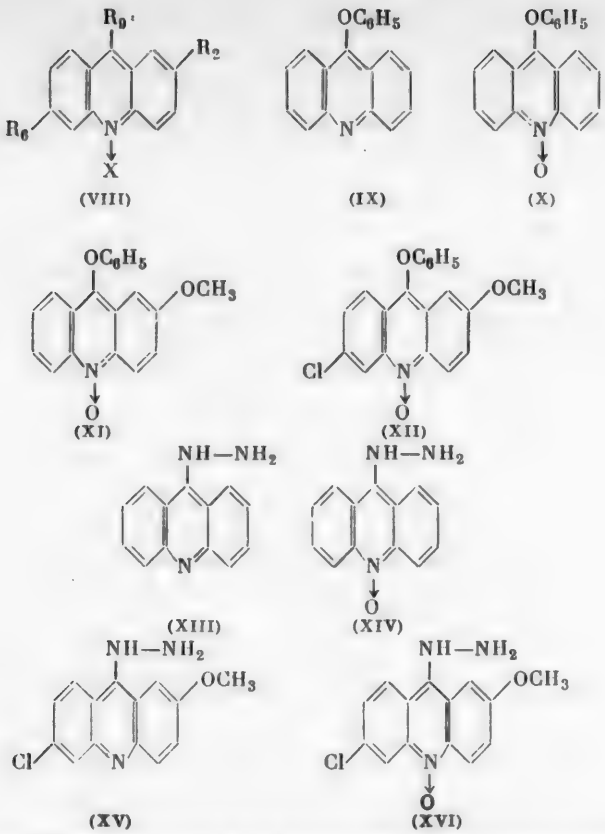


(VIII) (IX) (X)

(XI) (XII)

(XIII) (XIV)

(XV) (XVI)

The dielectric constants ϵ were determined by the heterodyne method in benzene solutions at 25° in an apparatus where the density $\underline{d}$ was measured simultaneously with a torsion balance.

The total polarization at infinite dilution (P_∞) was calculated by Hedestrand's method [4] from the experimental data for ϵ and $\underline{d}$. The electron polarization P_e was calculated as the molecular refraction; the refraction of N → O was calculated from the refraction of pyridine N-oxide. The atomic polarization P_a was neglected, as, for the compounds studied, the orientation polarization had a large value and the values of P_a included in it had no substantial effect on the value of the dipole moment.

The results of the dipole-moment measurements are presented in Table 1.

For comparison with the experimental values of the dipole moments, the vector sums of the bond moments were calculated ($\mu_{calc.}$), starting from the dipole moments of the simplest molecules and bonds. In the cases where different molecular configurations were theoretically possible, vector sums were calculated for all these configurations (only the calculated values which are closest to the experimental values are given in Tables 2 and 3).

For convenience in discussion, all the results for the experimental and calculated values of dipole moments for phenazine (I) derivatives are given in Table 2 and those for acridine (VIII) derivatives, in Table 3.

The data presented in Table 2 show that the introduction of various substituents into position 2 of the phenazine molecule leads to a large dipole moment (Cl – 2.46 D, NO_2 – 6.61 D, NH_2 – 6.72 D), while the dipole moment of unsubstituted phenazine equals zero (No. 1, Table 2) and the dipole moment of phenazine N-oxide (No. 2, Table 2), which contains the comparatively polar N → O bond, equals 1.76 D. This is apparently connected with the asymmetry of the molecule, with the considerable interaction of the electron system of the substituent with the electron system of the heteroatom in position 10, and with the elongation of the dipole arising as a result of this.

The dipole moment of 2-chlorophenazine N-oxide (No. 4, Table 2) is only slightly greater than the dipole moment of the unoxidized base (2.69 D instead of 2.46 D) and its value is close to the vector sum of the moments

TABLE 1

Formula No. in text	Name of substance	P_∞	P_e	$\mu_{exp} \cdot 10^{18}$
(II)	2-Chlorophenazine	179.966	55.318	2.46
(III)	2-Chlorophenazine N-oxide	209.654	60.288	2.69
(IV)	2-Chlorophenazine dioxide	271.672	65.258	3.16
(V)	2-Nitrophenazine	956.877	52.938	6.61
(VI)	2-Nitrophenazine N-oxide	764.089	57.908	5.85
(VII)	2-Aminophenazine	986.539	53.878	6.72
(IX)	9-Phenoxyacridine	217.408	97.947	2.40
(X)	9-Phenoxyacridine N-oxide	553.502	102.917	4.67
(XI)	2-Methoxy-9-phenoxyacridine N-oxide	696.147	108.232	5.33
(XII)	2-Methoxy-6-chloro-9-phenoxyacridine N-oxide	1011.887	112.970	6.60
(XIII)	9-Hydrazinoacridine	820.753	79.135	5.99
(XIV)	9-Hydrazinoacridine N-oxide	909.346	84.105	6.32
(XV)	2-Methoxy-6-chloro-9-hydrazinoacridine	1238.047	89.315	7.45
(XVI)	2-Methoxy-6-chloro-9-hydrazinoacridine N-oxide	1493.718	94.285	8.23

TABLE 2

Expt. No.	Formula No. in text	X	Y	R_2	$\mu_{exp} \cdot 10^{18}$	$\mu_{calc} \cdot 10^{18}$
1	—	—	—	—	0	0
2	—	$\rightarrow$O	—	—	1.76 [1]	—
3	(II)	—	—	Cl	2.46	1.55
4	(III)	$\rightarrow$O	—	Cl	2.69	2.75
5	(IV)	$\rightarrow$O	$\rightarrow$O	Cl	3.16	2.86
6	(V)	—	—	NO_2	6.61	3.95
7	(VI)	$\rightarrow$O	—	NO_2	5.85	4.89
8	(VII)	—	—	NH_2	6.72	1.53

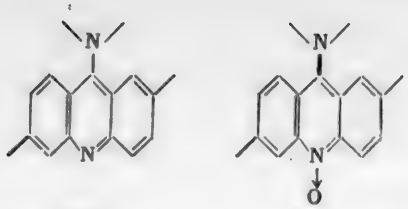
of the C−Cl and N $\rightarrow$ O bonds (2.75 D). On the other hand, the dipole moment of 2-nitrophenazine N-oxide is less than the dipole moment of the unoxidized base by approximately 0.8 D. 2-Aminophenazine has the greatest polarity ($\mu_{exp.}$ = 6.72 D).

The data given in Table 3 show that the molecules of the 9-phenoxy derivative are more polar than the corresponding 9-chloro derivative. The introduction of a methoxyl group into position 2 and a chlorine into position 6, considerably increases the dipole moment of 9-phenoxyacridine derivative. The vector sums of the moments, calculated for free rotation of the phenoxy groups, are the closest to the experimental values.

9-Hydrazinoacridine has a very large dipole moment (5.99 D), which considerably exceeds the dipole moment of 9-aminoacridine (4.13 D). The calculated dipole moment is much less than the experimental (the difference is 2.57 D). The introduction of a methoxyl group into position 2 and a chlorine into position 6 of the acridine molecule, as in the case of 9-phenoxy derivatives, sharply increases the dipole moment of the molecule.

In all cases, there was an increase in the dipole moments in going from the unoxidized derivatives of acridine to their N-oxides.

Comparison of our data, characterizing the polarity of molecules of 9-hydrazinoacridines, with data on the dipole moments of 9-aminoacridines [5], leads to the conclusion that molecules of type (A) are unusually polar and that



(A) (B)

the introduction of an oxide oxygen into them further increases the dipole moment of the molecule [type (B)].

Taking into account the fact that among acridine derivatives of type (A) there are many physiologically active substances, one may consider that substances of type (B), the first representative of which we synthesized recently, may acquire even greater interest for testing their biological activities, as the introduction of an oxide oxygen generally imparts valuable biological properties.

TABLE 3

Expt. No.	Formula No. in text	X	R_1	R_2	R_3	$\mu_{exp.} \cdot 10^{18}$	$\mu_{calc.} \cdot 10^{18}$
1	—	—	—	—	—	1.84 [1]	—
2	—	→O	—	—	—	4.08 [1]	—
3	—	—	Cl	—	—	0 [1]	—
4	(IX)	—	OC_6H_5	—	—	2.40	2.56
5	(X)	→O	OC_6H_5	—	—	4.67	4.34
6	(XI)	→O	OC_6H_5	OCH_3	—	5.33	4.97
7	(XII)	→O	OC_6H_5	OCH_3	Cl	6.60	6.55
8	(XIII)	—	$NH-NH_2$	—	—	5.99	3.42
9	(XIV)	→O	$NH-NH_2$	—	—	6.32	5.35
10	(XV)	—	$NH-NH_2$	OCH_3	Cl	7.45	5.08
11	(XVI)	→O	$NH-NH_2$	OCH_3	Cl	8.23	5.21
12	—	—	NH_2	—	—	4.13 [5]	3.28
13	—	—	NH_2	OCH_3	Cl	6.73 [5]	4.95

SUMMARY

1. Measurements were made of the dipole moments of 14 substances which are derivatives of phenazine and acridine and their N-oxides.

2. An investigation was made of the interaction of the N → O bond in phenazine and acridine N-oxides with various substituents in the heterocyclic ring.

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INVESTIGATION OF STRUCTURAL FEATURES AND CHEMICAL CONVERSIONS OF CARBAZOLE AND SOME OF ITS DERIVATIVES

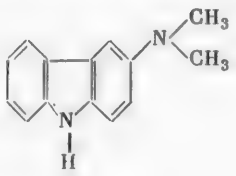
II. SOME PROPERTIES OF 3-AMINOCARBAZOLE AND ITS DERIVATIVES

S.I. Omel'chenko and Z.V. Pushkareva

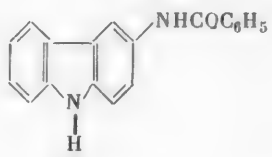
Despite the fact that many papers have been devoted to the synthesis of 3-aminocarbazole, the properties of this compound have not been studied in detail. There are only descriptions of the acetylation reaction [1, 2] and of some 9-substituted 3-aminocarbazoles with physiological activity [3-6].

In order to extend the knowledge of 3-aminocarbazole, we studied the alkylation, acylation and carboxymethylation of this compound and also the ultraviolet absorption spectra of all the derivatives obtained.

The methylation with dimethyl sulfate proceeded at room temperature in an alkaline medium with the formation of 3-dimethylaminocarbazole (I) with m.p. 135-140° (decomp.).



(I)

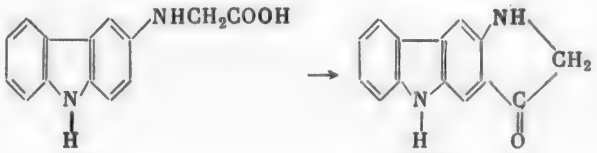


(II)

Depending on the conditions, the acetylation of 3-aminocarbazole with acetic anhydride could give either the mono-, di- or triacetyl derivatives.

The monobenzoyl derivative (II) could be obtained by reacting 3-aminocarbazole with benzoyl chloride in the presence of sodium alcoholate.

We were interested in carboxymethylation for the possibility of obtaining 3-carbazylglycine (III), an analog of phenylglycine, which is a starting material in the synthesis of indigoid dyes.

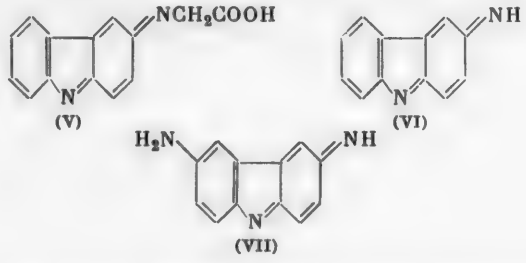


(III) (IV)

It was found that 3-aminocarbazole did not react with chloroacetic acid, despite the fact that all possible conditions were tried. Compound (III) was obtained only when bromoacetic acid was used as the alkylating agent; the product was isolated as a greenish-gray powder with m.p. 220° (decomp.).

Attempts to close the oxindole ring [(III) → (IV)] both by alkaline fusion and with the addition of various water-abstracting agents in an acid medium were unsuccessful. Carbazylglycine showed extreme stability in alkaline media and was decomposed quite quickly in acids. In working with this compound we noticed its interesting

tendency to change into a black product with a sharp m.p. of 150° on standing in air in organic solvents; in all probability this product was the corresponding quinonediimine (V).



Subsequently, black products were obtained from unsubstituted 3-aminocarbazole (VI) and 3,6-diaminocarbazole (VII) under slightly different conditions.

Comparison of the ultraviolet absorption spectra of the black products obtained with the spectra of carbazole and 3-aminocarbazole (Fig. 1) confirmed the hypothesis that these substances had structures of the quinonediimine type (their spectra were similar to each other and differed sharply from the spectra of the original carbazole and 3-aminocarbazole).

Considering the singularity of 3-aminocarbazole, observed in studying its simple reactions, attempts were made to explain the peculiarities of its structure by examining its ultraviolet absorption spectra.

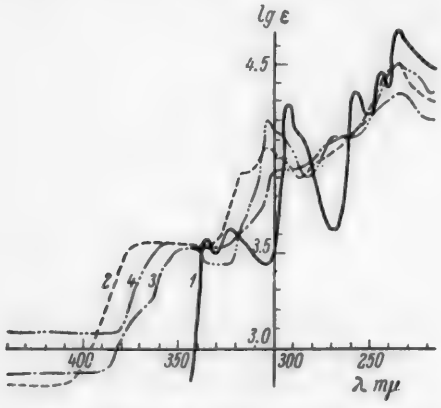


Fig. 1. Absorption spectrum curves: 1) carbazole; 2) quinonediimine of 3-aminocarbazole; 3) quinonediimine of 3-carbazylglycine; 4) quinonediimine of 3,6-diaminocarbazole.

As the idea of nitro derivatives of carbazole having a quinoid structure in an alkaline medium is put forward in the literature [7], we studied the spectra of 3-nitrocarbazole derivatives (Fig. 2). The unexpected similarity of the spectral curves of 3-nitrocarbazole in alkaline and neutral media indicates the absence of the quinoid form in alkaline solutions, or the presence of the latter in a neutral medium. The introduction of substituents into position 9 (9-methylcarbazole and 9-nitrocarbazole), which excludes the possibility of quinoid-form formation, did not produce any essential changes in the spectral curves (Fig. 2), indicating the absence of quinoid forms of 3-nitrocarbazole.

The spectrum of 3-aminocarbazole (Fig. 3) is characterized by the presence of a deep minimum at 312 mμ; the sections to the right and to the left of the main maximum in the carbazole spectrum are considerably changed. 3-Aminocarbazole hydrochloride has a spectrum which is similar to the carbazole spectrum (Fig. 3). The peculiarity of the 3-aminocarbazole curve is apparently connected with the presence of an interaction between the electron systems of the amino and imino groups of the compound and this is confirmed by examining the spectral curves of 3-dimethylaminocarbazole and 9-methyl-3-aminocarbazole (Fig. 4). The introduction of such strong electron-donor residues as acetyl and benzoyl into the amino group, leads to a substantial change in the original spectrum of the amine (Fig. 5).

EXPERIMENTAL

3-Dimethylaminocarbazole (I). 0.5 ml of dimethyl sulfate and 1 ml of 35% NaOH was added to a mixture of 30 ml of water, 20 ml of acetone and 1 g of 3-aminocarbazole; the mixture was shaken for 15 minutes, second portions of dimethyl sulfate and alkali added and shaking continued for one hour. The whole precipitate dissolved. The acetone was distilled off on a water bath, the aqueous solution adjusted to pH 9 and the brown oil which formed was separated from the aqueous layer and dissolved in anhydrous alcohol. (I) was precipitated from the alcohol solution with absolute ether in the form of a white, finely crystalline precipitate with m.p. 135-140°.

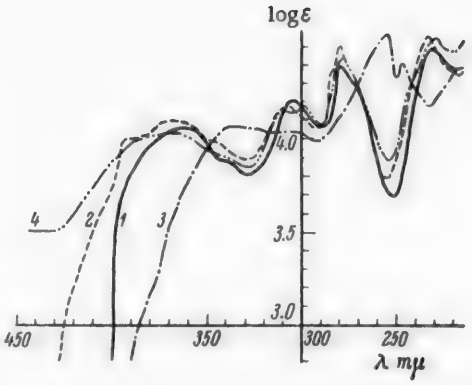


Fig. 2. Absorption spectrum curves: 1) 3-nitrocarbazole; 2) N-methyl-3-nitrocarbazole; 3) N-nitroso-3-nitrocarbazole; 4) 3-nitrocarbazole in an alkaline medium.

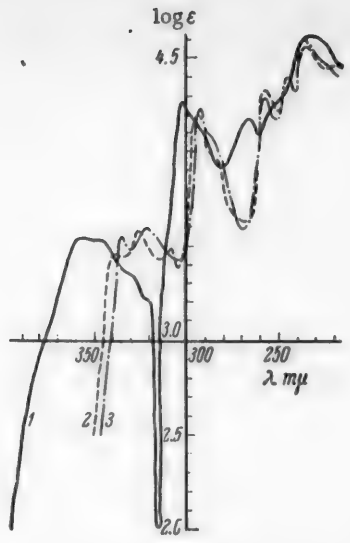


Fig. 3. Absorption spectrum curves: 1) 3-aminocarbazole; 2) 3-aminocarbazole hydrochloride; 3) carbazole.

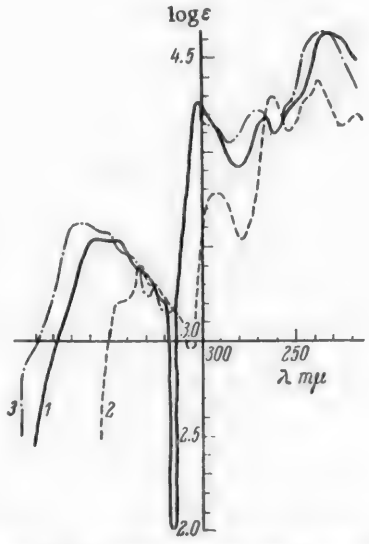


Fig. 4. Absorption spectrum curves: 1) 3-aminocarbazole; 2) 3-dimethylaminocarbazole; 3) N-methyl-3-aminocarbazole.

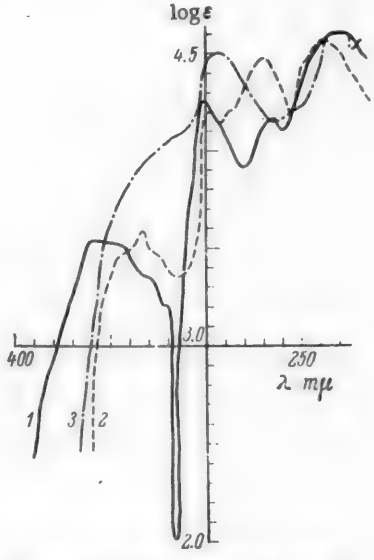


Fig. 5. Absorption spectrum curves: 1) 3-aminocarbazole; 2) 3-monoacetylaminocarbazole; 3) 3-benzoylaminocarbazole.

The yield was 0.6 g (57%). Substance (I) could not be diazotized, indicating the presence of substituents on the amino group.

Found %: N 6.87. $C_{13}H_{11}ON$. Calculated %: N 7.10.

3-Benzoylaminocarbazole (II). 1 g of 3-aminocarbazole was mixed with 15 ml of sodium alcoholate and 6 ml of benzoyl chloride added carefully with stirring and cooling. The mixture was kept without stirring for a day and the white, crystalline precipitate filtered off, washed with water and recrystallized from alcohol and acetone. The yield was 1.20 g (81.7%) and the m.p. 265°.

Found %: N 9.95. $C_{19}H_{14}ON_2$. Calculated %: N 9.82.

Substance (II) could not be diazotized and would not couple.

3-Carbazylglycine (III). 1.82 g of 3-aminocarbazole was dissolved in 100 ml of acetone and to the solution was added 1.4 g of bromoacetic acid, neutralized in the cold with 5 ml of 2 N sodium hydroxide solution. The reaction mixture was shaken for 30 minutes, heated on a boiling water bath for 0.5 hours and kept for 12 hours at room temperature. The solution was then diluted with 100 ml of water, the acetone distilled off and the precipitate formed filtered off and reprecipitated from ammonia solution with hydrochloric acid. We obtained 1.2 g of (III) with m.p. 120° (decomp.).

Found %: N 11.66. $C_{14}H_{12}O_2N_2$. Calculated %: N 11.57.

The substance could not be diazotized. It could not be obtained in a crystalline form.

Quinonediimine of 3-carbazylglycine. 2 g of (III) was dissolved in 50 ml of alcohol and the solution kept in air at room temperature for 3-4 hours and diluted with water; substance (III) was extracted with ether and distillation of the ether extract yielded 1.5 g of a uniform black product with m.p. 175-180°.

Found %: N 11.52. $C_{14}H_{10}O_2N_2$. Calculated %: N 11.76.

The quinonediimines of 3-aminocarbazole and 3,6-diaminocarbazole were prepared similarly, though the alcohol solutions of the starting materials were shaken in air for 1.5 days.

The ultraviolet absorption spectra were measured on an SF-4 spectrophotometer using alcohol solutions.

SUMMARY

1. The alkylation, acylation, benzoylation and carboxymethylation of 3-aminocarbazole were performed and demonstrated the essential difference between the amino group of 3-aminocarbazole and the amino groups of normal aromatic amines.

2. The tendency of 3-aminocarbazole, 3,6-diaminocarbazole and, especially, 3-carbazylglycine to undergo oxidative conversion into the corresponding quinonediimines was observed.

3. Comparison of the ultraviolet spectra of 3-aminocarbazole derivatives showed that its chemical singularity was caused by interaction of the electron systems of the heteroatom and the nitrogen of the amino group.

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CATALYTIC DEHYDROCONDENSATION OF TRIALKYLSILANES WITH ALCOHOLS IN THE PRESENCE OF METAL CHLORIDES

B.N. Dolgov, N.P. Kharitonov, N.E. Glushkova and Iu.I. Khudobin

The present work is a continuation of our investigations on the catalytic dehydrocondensation of trialkyl- and triarylsilanes with hydroxy, oxo and polyhydroxy organic compounds.

Previously [1] the catalysts used for dehydrocondensation of R_3SiH with alcohols were alcoholates of the alkali metals and, in the presence of these, the yields of trialkylalkoxysilanes reached 80-90%.

The present report describes the use of small amounts of various metal chlorides, of which the most active were $ZnCl_2$ and $SnCl_2$, in the dehydrocondensation of R_3SiH with alcohols.

The rate of the reaction of R_3SiH with alcohols depended on the nature and the amount of the metal chloride. Increasing the amount of chloride in the reaction mixture from 0.05 to 1 g led to a noticeable growth in the reaction rate, but a further increase did not affect the process. This was tried on the reaction of methanol with triethylsilane at a ratio of 2:1 (Table 1).

TABLE 1*

Catalyst	Amount of catalyst (in g)	Reaction time (in minutes)	Yield of $(C_2H_5)_3SiOCH_3$ (in %)
$ZnCl_2$	1	90	97.7
$CdCl_2$	1	2610	97.2
Cu_2Cl_2	1	2700	0
$SnCl_2$	1	60	98.0
$ZnCl_2$	0.05	4080	96.8
$ZnCl_2$	0.1	3660	97.0
$ZnCl_2$	0.2	960	96.9
$ZnCl_2$	0.5	360	97.7
$ZnCl_2$	3	90	98.4

*Experiments at 120-125°.

An increase in the length of the alkyl radical from CH_3 to n-C_4H_9, in alcohols of normal structure, lowered the reaction rate (Table 2, Expts. 1-3 and 5). In the case of radicals with an iso-structure, steric hindrance lowered the reaction rate considerably (Table 2).

In contrast to the dehydrocondensation of R_3SiH with tert.-butyl alcohol in the presence of alkali metals [1], this reaction could not be realized at normal pressure or in an autoclave in the presence of $ZnCl_2$ and $SnCl_2$ (Table 2, Expts. 11 and 12).

The structure of the trialkylsilane also had a substantial effect on the reaction rate (Table 3). When one of the ethyl radicals in triethylsilane was substituted by methyl, the rate of reaction with n-butyl alcohol was increased by a factor of 2 with $SnCl_2$ (Expts. 1 and 3) and a factor of 3.5 with $ZnCl_2$ (Expts. 2 and 4) and with isobutyl alcohol it was increased by a factor of 1.5 in the case of $SnCl_2$ and a factor of 4.5 in the case of $ZnCl_2$.

TABLE 2*

Expt. No.	Formula of alcohol	Formula of trialkylsilane	$MeCl_2$ catalyst (nature of Me)	Reaction time (in min)	Yield of R_3SiOR' (in %)
1	CH_3OH	$(C_2H_5)_3SiH$	Zn	240	98.0
2	CH_3CH_2OH	$(C_2H_5)_3SiH$	Zn	270	96.9
3	$CH_3CH_2CH_2OH$	$(C_2H_5)_3SiH$	Zn	300	98.6
4	$(CH_3)_2CHOH$	$(C_2H_5)_3SiH$	Zn	480	96.1
5	$CH_3CH_2CH_2CH_2OH$	$(C_2H_5)_3SiH$	Zn	330	96.0
6	$(CH_3)_2CHCH_2CH_2OH$	$(C_2H_5)_3SiH$	Sn	60	98.0
7	$(CH_3)_2CHCH_2OH$	$(C_2H_5)_3SiH$	Zn	3600	86.6
8	$(CH_3)_2CHCH_2OH$	$(C_2H_5)_3SiH$	Sn	75	93.4
9	$CH_3CHCH_2CH_3$ (OH)	$CH_3(n.\text{-}C_4H_9)_2SiH$	Zn	540	86.9
10	$CH_3CHCH_2CH_3$ (OH)	$CH_3(n.\text{-}C_4H_9)_2SiH$	Sn	90	91.4
11	$(CH_3)_3COH$	$CH_3(n.\text{-}C_4H_9)_2SiH$	Zn	600	0
12	$(CH_3)_3COH$	$CH_3(n.\text{-}C_4H_9)_2SiH$	Sn	600	0

*Experiments at 120-125°.

TABLE 3

Expt. No.	Formula of trialkylsilane*	$MeCl_2$ catalyst (nature of Me)	Reaction time (in minutes)	Yield of R_3SiOR' (in %)
1	$(C_2H_5)_3SiH$	Sn	60	96.0
2	$(C_2H_5)_3SiH$	Zn	330	96.9
3	$CH_3(C_2H_5)_2SiH$	Sn	30	85.5
4	$CH_3(C_2H_5)_2SiH$	Zn	90	92.9
5	$CH_3(n.\text{-}C_3H_7)_2SiH$	Sn	45	99.3
6	$CH_3(n.\text{-}C_3H_7)_2SiH$	Zn	105	97.3
7	$CH_3(n.\text{-}C_4H_9)_2SiH$	Sn	45	99.3
8	$CH_3(n.\text{-}C_4H_9)_2SiH$	Zn	110	90.3
9	$(C_2H_5)_3SiH$	Sn	75	96.0
10	$(C_2H_5)_3SiH$	Zn	600	96.9
11	$CH_3(C_2H_5)_2SiH$	Sn	45	93.4
12	$CH_3(C_2H_5)_2SiH$	Zn	135	92.7
13	$CH_3(n.\text{-}C_3H_7)_2SiH$	Sn	45	85.7
14	$CH_3(n.\text{-}C_3H_7)_2SiH$	Zn	135	82.0
15	$CH_3(n.\text{-}C_4H_9)_2SiH$	Zn	150	90.0
16	$CH_3(n.\text{-}C_4H_9)_2SiH$	Sn	50	89.9

*Experiments 1-8 were performed with $n\text{-}C_4H_9OH$ and experiments 9-16 with primary isobutyl alcohol. The temperature was 120-125°.

The dehydrocondensation of R_3SiH with alcohols in the presence of alkali metal alcoholates [1] or metal chlorides proceeds by an ion-chain mechanism.

As a result of our experiments we synthesized 13 trialkylalkoxysilanes (seven of them for the first time). The physical properties of the new substances are presented in Table 4. The physical properties of the known silanes corresponded to the properties that we gave for these compounds previously [1].

The method presented of synthesizing trialkylalkoxysilanes by condensing R_3SiH with anhydrous alcohols in the presence of metal chlorides, is a general one for alkoxylation of the Si—H bond. The method makes it possible to obtain trialkylalkoxysilanes in a pure form. As special experiments showed, side products are not formed in this reaction.

TABLE 4

Trialkylalkoxysilanes

Formula	Boiling point	d_4^{20}	n_D^{20}	MR_D*		Molecular weight		Si content (in %)	
				calc.	found	calc.	found	calc.	found
$CH_3(C_2H_5)_2SiOCH_2CH_2CH_2CH_3$ **	172.2°	0.8060	1.4125	54.2	53.9	174.4	175.2, 175.0	16.1	15.8, 16.0
$CH_3(n.\text{-}C_3H_7)_2SiOCH_2CH_2CH_2CH_3$ ***	202.5	0.8094	1.4200	63.4	63.3	202.4	202.2, 202.0	13.9	13.7, 14.0
$CH_3(n.\text{-}C_4H_9)_2SiOCH_2CH_2CH_2CH_3$	235.5	0.8154	1.4272	72.7	72.7	230.5	227.8, 228.0	12.2	12.4, 12.1
$CH_3(C_2H_5)_2SiOCH_2CH(CH_3)_2$	166.5	0.8009	1.4098	54.2	53.9	174.4	173.1, 175.1	16.1	16.0, 15.9
$CH_3(n.\text{-}C_3H_7)_2SiOCH_2CH(CH_3)_2$	197.3	0.8046	1.4172	63.4	63.2	202.4	200.8, 201.8	13.9	14.1, 14.0
$CH_3(n.\text{-}C_4H_9)_2SiOCH_2CH(CH_3)_2$	228.3	0.8114	1.4250	72.7	72.4	230.5	229.0, 227.8	12.2	12.6, 12.3
$CH_3(n.\text{-}C_4H_9)_2SiOCH(CH_3)CH_2CH_3$	226.6	0.8132	1.4260	72.7	72.5	230.5	232.5, 227.4	12.2	12.3, 12.5

*Molecular refractions were calculated according to data in [4].

**Found %: C 61.8, 61.8; H 12.9, 12.8. $C_9H_{22}SiO$. Calculated %: C 62.0; H 12.8.

***Found %: C 65.3, 65.4; H 12.9, 13.0. $C_{11}H_{26}SiO$. Calculated %: C 65.3; H 12.9.

EXPERIMENTAL

The trialkylsilanes were prepared by the Grignard method from $HSiCl_3$, CH_3SiHCl_2 and the appropriate alkyl halides. The constants and yields of the three trialkylsilanes are given in Table 5.

TABLE 5

Formula of trialkylsilane*	Boiling point	d_4^{20}	n_D^{20}	Yield (in %)
$CH_3(C_2H_5)_2SiH$	77.9°	0.7054	1.3984	41
$CH_3(n.\text{-}C_3H_7)_2SiH$	128.2	0.7337	1.4135	70
$CH_3(n.\text{-}C_4H_9)_2SiH$	172.9	0.7539	1.4242	72

*Data for $(C_2H_5)SiH$ was given previously [1]. The alcohols used in the reactions were distilled over metallic calcium and their constants agreed with literature data [2].

The zinc, cadmium, tin and copper chlorides were first dehydrated by the generally accepted procedure [3].

The procedures for synthesizing the trialkylalkoxysilanes and determining their physical constants and silicon contents were described by us previously [1]. The carbon and hydrogen in R_3SiOR were determined by combustion of microsamples of the material in an empty tube.*

As an example of the general procedure of trialkylalkoxysilane synthesis, the preparation of triethylmethoxysilane is presented below.

*The C and H contents were determined by Iu.N. Platonov, to whom the authors are grateful.

Triethylmethoxysilane. 6.5 g of methyl alcohol, 1.0 g of $ZnCl_2$ and 11.6 g of triethylsilane were boiled until the evolution of hydrogen ceased completely. The reaction was performed at 120-125°. When the reaction had proceeded for 61 hours, 2.4 liters of hydrogen had been evolved. The maximum temperature of the reaction mixture reached 135° at the end of the reaction. Distillation of the reaction mixture yielded 3.2 g of methyl alcohol and 14.2 g of triethylmethoxysilane.

SUMMARY

1. A study was made of the reaction of trialkylsilanes with monohydric alcohols in the presence of metal chlorides.

2. It was shown that some metal chlorides catalyze the dehydrocondensation of R_3SiH with alcohols. The most effective catalysts are $SnCl_2$ and $ZnCl_2$. The yields of trialkylalkoxysilanes reached 99%.

3. A relation was established between the course of the reaction and the structure of R_3SiH and the alcohol, and the nature and amount of the catalyst.

4. Seven new trialkylalkoxysilanes were prepared.

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CATALYTIC DEHYDROCONDENSATION OF TRIALKYLSILANES WITH GLYCOLS

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We previously investigated the catalytic dehydrocondensation of trialkylsilanes with monohydric alcohols. A relation was established between the course of the reaction and the structure of the alcohol and the trialkylsilane and the nature of the alkali metal alcoholate added as a catalyst. It was shown that it was possible to replace the hydrogen atom attached to the silicon by primary, secondary and tertiary alkoxy groups [1].

The present paper reports the catalytic dehydrocondensation of trialkylsilanes with glycols.

Existing literature data show that it is possible to react glycols with $SiCl_4$ and alkyl(aryl) silane chlorides. Thus, dimethyldichlorosilane and ethylene glycol condense to a dimer and other glycols to monomeric dimethylalkylidenedioxysilanes [2]. Sprung and Nelson [3] prepared trimethylsilyl derivatives from trimethylchlorosilane and glycols. Trimethylchlorosilane and $SiCl_4$ with 1,4-butanediol in dioxane, and without it, formed only linear and cross-linked polymers [4]. Hahn [5, 6] treated 1,3- and 1,4-butanediols and diglycol with $SiCl_4$ to isolate monomers with 6, 7 and 8-membered rings. There is no mention of the direct reaction of trialkylsilanes with glycols in the literature.

In studying the catalytic dehydrocondensation of R_3SiH with glycols, we started from $(C_2H_5)_3SiH$, $(C_3H_7)_3SiH$, $(C_4H_9)_3SiH$ and $C_2H_5(C_4H_9)_2SiH$. The dihydric alcohols used were ethylene glycol, 1,2-propanediol, 1,3-, 1,4- and 2,3-butanediol and ethylene diglycol.

As with monohydric alcohols, the glycols did not react with the trialkylsilanes without a catalyst. When heated in a quartz vessel at normal pressure for 100 hours, a mixture of triethylsilane and 1,4-butanediol did not react. In the presence of catalysts (traces of alkali metal glycolates) trialkylsilanes reacted with glycols by the general scheme

$$2R_3SiH + C_nH_{2n}(OH)_2 \xrightarrow[\text{where } M = Li,\ Na,\ K.]{C_nH_{2n}(OM)_2} C_nH_{2n}(OSiR_3)_2 + 2H_2.$$

The molar ratio of trialkylsilane, glycol and alkali metal was kept constant in all the experiments (0.15 : : 0.05 : 0.005). The criterion for completion of the reaction was the evolution of the calculated amount of hydrogen.

The advantages of this method of preparing di(trialkylsiloxy)alkanes, in contrast to the synthesis through alkylchlorosilanes, include not only the simplicity of the procedure, but the high yields and the purity of the products formed.

The catalytic dehydrocondensation of R_3SiH with glycols was investigated under the conditions which we normally use and at 160 and 180° in a thermostat. It was established that the reaction proceeded more rapidly at 180° than at 160°. The reaction rate depended on the structure of the glycol and of the trialkylsilane. When the length of the alkyl radicals in R_3SiH was increased, the reaction rate decreased (Table 1).

The calculated values of the activation energy for the reaction of 1,4-butanediol with various trialkylsilanes also confirmed this hypothesis. For example, the activation energy (in kcal/mole) for the formation of 1,4-di-(triethylsiloxy)butane equaled 32.46, for 1,4-di(tripropylsiloxy)butane, 35.52, for 1,4-di(tributylsiloxy)butane, 36.94 and for 1,4-di(ethyldibutylsiloxy)butane, 35.51.

TABLE 1

Formula of trialkylsilane	Reaction time (in minutes)					
	1,4-butanediol		1,3-butanediol		2,3-butanediol	
	160°	180°	160°	180°	160°	180°
$(C_2H_5)_3SiH$	90	75	18	15	140	20
$C_2H_5(C_4H_9)_2SiH$	115	110	30	25	150	55
$(C_4H_9)_3SiH$	320	210	60	35	170	65

The structure of the glycol had a considerable effect on the reaction rate. Ethylene glycol reacted considerably more slowly than 1,4-butanediol and ethylene diglycol. Diprimary butanediol reacted more slowly than disecondary and secondary-primary, more rapidly than the other isomeric glycols (Tables 1 and 2).

TABLE 2

Reaction of Trialkylsilanes with Glycols*

Starting reagents		Reaction time (in minutes)	Reaction product yield (in %)
trialkylsilane	glycol		
$(C_2H_5)_3SiH$	$HO(CH_2)_4OH$	165	74.5
$(C_2H_5)_3SiH$	$HO(CH_2)_2CHOHCH_3$	30	73.1
$(C_2H_5)_3SiH$	$CH_3(CHOH)_2CH_3$	105	74.3
$(C_2H_5)_3SiH$	$HOCH_2CHOHCH_3$	110	81.6
$(C_3H_7)_3SiH$	$HO(CH_2)_4OH$	148	84.3
$(C_3H_7)_3SiH$	$HO(CH_2)CHOHCH_3$	14	87.9
$(C_3H_7)_3SiH$	$CH_3(CHOH)_2CH_3$	26	88.5
$(C_4H_9)_3SiH$	$HO(CH_2)_4OH$	20	85.4
$(C_4H_9)_3SiH$	$HO(CH_2)_2CHOHCH_3$	17	87.5
$(C_4H_9)_3SiH$	$CH_3(CHOH)_2CH_3$	20	83.2
$C_2H_5(C_4H_9)_2SiH$	$HO(CH_2)_4OH$	75	97.6
$C_2H_5(C_4H_9)_2SiH$	$HO(CH_2)_2CHOHCH_3$	5	75.9
$C_2H_5(C_4H_9)_2SiH$	$CH_3(CHOH)_2CH_3$	15	72.1
$C_2H_5(C_4H_9)_2SiH$	$HOCH_2CHOHCH_3$	60	88.5
$C_2H_5(C_4H_9)_2SiH$	$HOCH_2CHOHCH_3$ **	150	82.1
$C_2H_5(C_4H_9)_2SiH$	$HOCH_2CHOHCH_3$ ***	3780	66.3
$C_2H_5(C_4H_9)_2SiH$	$HO(CH_2)_2OH$	560	89.3
$C_2H_5(C_4H_9)_2SiH$	$HO(CH_2)_2O(CH_2)_2OH$	40	88.7

*The experiments were performed at the boiling point of the mixture. The catalyst was potassium glycolate.

**Catalyst – sodium glycolate.

***Catalyst – lithium glycolate.

As in the case of monohydric alcohols [1], the reaction of R_3SiH with glycols was affected by the nature of the alkali metal used in the catalyst. With an increase in the atomic number of the alkali metal (from lithium to potassium), the reaction rate increased (Table 2). The alcoholates or glycolates, formed in small amounts, played the part of basic catalysts.

In analogy with the mechanism of the reaction of R_3SiH with monohydric alcohols [1], one can assume that the reaction of R_3SiH with glycols probably proceeds by an ion-chain mechanism also.

As a result of the work, we synthesized 16 di(trialkylsiloxy)alkanes, which are not described in the literature (Table 3).

EXPERIMENTAL

Starting reagents. a) The trialkylsilanes were prepared by the action of RMgX on $HSiCl_3$ (or $C_2H_5SiCl_2H$). The constants of the first three compounds corresponded with data which we presented previously [1]. Ethyldibutylsilane had the following constants:

TABLE 3

Properties of Di(trialkylsiloxy)alkanes

Name of compound	Boiling point	Pressure (mm)	d_4^{20}	n_D^{20}	Molecular weight*		Content (in %)**					
							Si		C		H	
					calc.	found	calc.	found	calc.	found	calc.	found
1,4-Di(triethylsiloxy)butane	203.0°	10	0.8765	1.4397	318.6	315.3, 313.7	17.6	17.4, 17.3	60.3	60.2, 60.5	12.0	12.2, 12.1
1,3-Di(triethylsiloxy)butane	198.0	14	0.8728	1.4388	318.6	311.9, 314.1	17.6	17.4, 17.6	60.3	59.8, 60,1	12.0	11.9, 12.3
2,3-Di(triethylsiloxy)butane	192.5	13	0.8791	1.4410	318.6	316.0, 314.4	17.6	17.5, 17.6	60.3	60.8, 60.7	12.0	12.1, 12.1
1,2-Di(triethylsiloxy)propane	177.5	9.5	0.8754	1.4372	304.6	301.2, 302.8	18.4	18.4, 18.3	59.1	59.5, 59.4	11.9	12.3, 12.1
1,4-Di(tripropylsiloxy)butane	224.0—224.5	3-3.5	0.8635	1.4458	402.8	398.2, 394.3	13.9	13.9, 13.9	65.6	65.2, 63.3	12.5	12.3, 12.1
1,3-Di(tripropylsiloxy)butane	206.5	5	0.8602	1.4435	402.8	396.2, 393.9	13.9	13.9, 14.0	65.6	65.3, 65.4	12.5	12.3, 12.3
2,3-Di(tripropylsiloxy)butane	217.5	8	0.8633	1.4447	402.8	397.2, 392.4	13.9	13.8, 13.9	65.6	65.3, 65.1	12.5	12.3, 12.1
1,4-Di(tributylsiloxy)butane	292.5	17.5	0.8613	1.4507	486.9	482.7, 484.0	11.5	11.5, 11.2	69.0	68.8, 68.5	12.6	12.4, 12.3
1,3-Di(tributylsiloxy)butane	290.0—290.5	15—16	0.8579	1.4490	486.9	483.1, 481.7	11.5	11.0, 11.2	69.0	69.2, 69.5	12.6	12.7, 12.5
2,3-Di(tributylsiloxy)butane	272.0—272.5	21—22	0.8581	1.4491	486.9	481.8, 485.2	11.5	11.2, 11.2	69.0	68.9, 69.2	12.6	12.3, 12.7
1,4-Di(ethyldibutylsiloxy)butane	205.0—205.3	3.5	0.8672	1.4480	430.8	427.8, 428.2	13.0	12.7, 12.5	66.9	66.4, 66.8	12.6	12.8, 12.7
1,3-Di(ethyldibutylsiloxy)butane	195.0—195.5	3.5-4	0.8652	1.4474	430.8	426.5, 425.9	13.0	12.9, 12.9	66.9	66.5, 67.0	12.6	13.0, 12.7
2,3-Di(ethyldibutylsiloxy)butane	245.5	12	0.8647	1.4474	430.8	427.8, 426.9	13.0	12.6, 12.8	66.9	64.9, 65.7	12.6	12.7, 12.8
1,2-Di(ethyldibutylsiloxy)propane	191.0—192.0	4.5-5.5	0.8677	1.4460	416.8	412.7, 413.3	13.5	13.4, 13.4	66.3	66.4, 66.7	12.6	12.6, 12.7
1,2-Di(ethyldibutylsiloxy)ethane	220.8—221.3	4—5	0.8687	1.4488	402.8	396.3, 398.5	13.9	13.7, 13.6	65.6	64.8, 63.9	12.5	12.6, 12.5
1,5-Di(ethyldibutylsiloxy)-3-oxapentane	292.1	2.5	0.8889	1.4502	446.8	443.5, 444.8	12.6	12.4, 12.3	64.5	63.9, 64.1	12.2	12.3, 12.4

*The molecular weight was determined cryoscopically in benzene.

**The authors are very grateful to M.N. Platonov, who performed the microanalytical determinations.

B.p. 194.0-194.5° (760.9 mm), $n^{20}D$ 1.4318, d^{20}_4 0.7666, MR_D 58.30; calc. 58.35.

b) The glycols were frozen at a temperature of minus 60-70°, separated from the water, boiled for 1-2 hours over metallic calcium and distilled 3-7 times over fresh portions of metallic calcium. The physical constants of the purified glycols corresponded with literature data [7, 8].

c) Lithium, sodium and potassium were chemically pure reagents.

Procedure. The dehydrocondensation of trialkylsilanes with glycols was performed in two ways.

A. At the boiling point of the mixture. As an example we will describe the synthesis of 1,2-di(ethyldibutylsiloxy)propane.

0.03 g of lithium was dissolved in 3.8 g of 1,2-propanediol, while cooled in a mixture of ice and salt. The lithium glycolate obtained was added to 25.8 g of ethyldibutylsilane. The mixture was boiled for 63 hours. The temperature of the reaction mixture reached 188° at the end of the reaction. 2.5 liters of hydrogen was evolved. The reaction mixture was vacuum distilled to give unchanged ethyldibutylsilane and 13.8 g (66.3%) of 1,2-di-(ethyldibutylsiloxy)propane with b.p. 188.5-189° (2.5-3 mm).

In all cases the distillate consisted of two components – di(trialkylsiloxy)alkane and unchanged trialkylsilane. The difference in the boiling points of the components was 100-150°, which simplified the problem of isolating the product in a satisfactorily pure form.

TABLE 4

V_t	Glycol reacted (mole %)	V_0	Time (min)	Reaction rate
14.8	20.1	13.5	5	2.71
19.9	27.2	18.3	10	1.83
28.3	38.5	25.9	20	1.29
35.7	48.6	32.6	30	1.08
56.2	76.4	51.3	60	0.86
69.2	94.0	63.2	90	0.73
72.2	98.0	66.0	180	0.36

E = 32.46 kcal/mole

B. In thermostats at 160 and 180°. Flasks with two arms were used for these experiments. In one arm was placed a sample of the glycol, with the alkali metal dissolved in it, and in the other, the trialkylsilane. The flask was connected to a 100-ml gas burette through a reflux condenser. The system was placed in a Heppler ultrathermostat filled with distilled dibutyl phthalate. The system was kept at the given temperature for ten minutes. The air was expelled and the reagents mixed. The hydrogen evolved was read off every 5-10 minutes. From these data graphs were plotted of reaction rate against time and the apparent activation energy calculated by the formula

$$E = \frac{2.3 \cdot R \lg \frac{k_1}{k_2} T_1 \cdot T_2}{T_1 - T_2},$$

where k is replaced by the amount of hydrogen evolved in the same time intervals and T_1 and T_2 are the absolute temperatures.

The data from two experiments at 160 and 180° are given below.

Triethylsilane and 1,4-butanediol (Table 4). We used 0.1351 g of 1,4-butanediol, 0.0079 g of potassium and 1.7918 g of $(C_2H_5)_3SiH$. The temperature in the thermostat was 160°. The temperature in the surrounding air was 21.0°. The atmospheric pressure was 769.22 mm and P_0 750.52 mm. The correction factor F = 0.9168. V_t was the volume of hydrogen liberated.

TABLE 5

v_t	Glycol reacted (mole %)	v_0	Time (min)	Reaction rate
23.0	35.5	20.7	2	10.3
26.0	40.9	23.4	3	7.8
28.0	43.2	25.2	4	6.3
29.5	45.7	26.6	5	5.3
33.4	51.7	30.1	10	3.0
38.0	58.9	34.3	15	2.3
39.5	61.2	35.6	20	1.7
42.0	65.2	37.9	30	1.2
44.5	69.0	40.1	40	1.0
51.0	79.0	46.0	60	0.76
54.0	83.8	48.7	75	0.65
69.0	90.0	62.4	140	0.45

E = 32.46 kcal/mole

Triethylsilane and 1,4-butanediol (Table 5). We used 0.1204 g of 1,4-butanediol, 0.0076 g of potassium and 2.6497 g of triethylsilane. The temperature in the thermostat was 180°. The temperature in the surrounding air was 23.0°. The atmospheric pressure was 764.3 mm and P_0 743.2 mm. The correction factor F = 0.9017. V_t was the volume of hydrogen liberated.

SUMMARY

1. A study was made of the catalytic dehydrocondensation of trialkylsilanes with glycols in the presence of lithium, sodium and potassium glycolates. The reaction is a simple and convenient method of synthesizing di(trialkylsiloxy)alkanes, which are formed in 80-90% yield.

2. We synthesized 16 di(trialkylsiloxy)alkanes which are not described in the literature.

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THE MECHANISM OF ACID OXIDATION BY MOLECULAR OXYGEN IN AN n-HEPTANE MEDIUM

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There are several papers in the literature on the oxidation of individual acids by bound oxygen or atmospheric oxygen in the presence of catalysts. The main products of the oxidation of propionic acid [1] with an alkaline potassium permanganate solution were oxalic acid and carbon dioxide. Oxidation of this acid with potassium bichromate in an acid medium gave mainly acetic acid and carbon dioxide. When oxidized with hydrogen peroxide, butyric acid [2] gave a whole series of products: acetic acid, carbon dioxide, acetone, ethyl alcohol and propionaldehyde. Kern [3] and Paquot and de Goursac [4] found methyl ketones in acid oxidation products. It is interesting to note that on oxidizing higher aliphatic acids with an even number of carbon atoms, with atmospheric oxygen in the presence of catalysts, the latter authors detected lower monocarboxylic acids with an even number of carbon atoms, as well as oxalic acid, in the reaction products.

It can be seen from this brief summary that the mechanism of acid oxidation depends on the conditions under which the experiments are carried out. Consequently, the rules governing the oxidation of individual acids in the presence of catalysts with different oxidizing agents cannot be generalized to cover the case of acid oxidation in a medium of an oxidizable hydrocarbon.

Therefore, it is interesting to study the oxidation of acids in a medium of an oxidizable hydrocarbon and by comparing the results with literature data, to try to find the basic characteristics of the oxidation mechanism in relation to the reactions' character and the molecular structure of the acids. Since acids are not only consumed but also formed during the reaction as a result of hydrocarbon oxidation, the most convenient method for solving this problem was to use labeled atoms.

In this investigation on acid oxidation we selected a simple system, which facilitated the analytical part of the work: we studied the oxidation of n-butyric and n-valeric acids in an n-heptane medium. In order to follow the behavior of both the functional group and the carbon chain of the acids, we synthesized n-butyric acid, labeled with radiocarbon in the carboxyl group and n-valeric acid, labeled in the α-position. In addition, we synthesized acetic acid, labeled in the carboxyl group so as to check its oxidizability under the given conditions.

To follow the behavior of the carboxyl group in the oxidized acid, the oxidation of n-heptane, with carboxyl-labeled n-butyric acid added, was carried out. We set up an activity balance for a two-hour experiment at 160° and 6 atm pressure and for a three-hour experiment at 180° and 8 atm pressure. The experimental results are given in the Table. The balance was set up with an accuracy of 2-3%. As the data in the Table show, of the oxidation products only the acid and the carbon dioxide were found to be active. The ketones were inactive. The balance indicated that within the limits of accuracy of the analysis, no other active reaction products were formed or they were unstable under the experimental conditions and were oxidized to carbon dioxide. It should be noted that the only gaseous labeled product was carbon dioxide.

The problem of the oxidizability of acetic acid under the given conditions was solved in the same way. n-Heptane with the addition of 0.02 mmole/ml of acetic acid, labeled in the carboxyl group, was oxidized for four hours. In this case as well, the only active reaction products were acid and carbon dioxide. About 0.1% of the activity was found in the carbon dioxide. Consequently, one may consider that under the experimental conditions the acetic acid was not appreciably decarboxylated.

An investigation of the oxidation of an acid labeled with radiocarbon in the carboxyl group does not make it possible to establish the reactions of the rest of the molecule after decarboxylation. In order to solve this

	Activity (counts/min) in experiments with acid added		
	n-butyric		acetic
	160°, 6 atm, 2 hr	180°, 8 atm, 3 hr	160°, 6 atm, 4 hr
Activity of acids from the experiment	23100	18200	Not determined quantitatively
Activity of CO_2 evolved	724	6760	$1.48 \cdot 10^4$
Ketone activity	–	–	–
Total	23824	24960	
Activity introduced	24400	24400	$1.32 \cdot 10^7$

problem we set up experiments with n-heptane to which n-valeric acid, labeled with radiocarbon in the α-methyl group, was added. The oxidation was carried out at 160° and 6 atm pressure. Of the reaction products, the acids, ketones and carbon dioxide were found to be active. The iodoform and acids formed in an iodoform reaction with the ketones were analyzed for activity content. The iodoform was found to be active and the acids inactive. Therefore, the α-methyl group was active in the ketones.

Due to the small amount of activity, introduced in the form of n-valeric acid and the small absolute amounts of acids which may be separated with paper chromatography, we have not yet been able to establish which of the individual acids, besides valeric acid, were active.

A series of conclusions may be drawn on the mechanism of acid oxidation from the experimental data obtained.

As has already been noted, on oxidizing butyric acid labeled with radiocarbon in the carboxyl group, all the activity was found to be in the acids and carbon dioxide. The activity balance set up indicated that quantitative oxidative decarboxylation occurred. The only gaseous reaction product was carbon dioxide. This experimental fact made it possible to follow the behavior of the acid's carboxyl group in any complex system of hydrocarbon oxidation products.

The reactions of the acid residue after decarboxylation may be established from the experimental data on the oxidation of n-valeric acid labeled in the α-position. The methyl ketone (labeled in the α-methyl group) found in the reaction products made it possible to determine unequivocally the position where the oxidizing agent attacked the acid molecule. The methyl ketone with a labeled α-methyl group may be formed from valeric acid, labeled in the α-position, only by the oxidizing agent attacking the acid's β-methylene group. Consequently, the following reaction took place: $CH_3CH_2CH_2C^{14}OOH \rightarrow CH_3CH_2COC^{14}H_3 + H_2O + CO_2$. Methyl ethyl ketone, carbon dioxide and water were formed.

The most reactive position in an acid molecule in the case of its oxidation is the β-CH_2 group, although the weakest C–H bond is at the α-CH_2 group (due to the effect of the adjacent carboxyl group).

Oxidation of hydrocarbons with atmospheric oxygen is a radical-chain type of reaction with degenerate branching. Apparently, in such reactions the direction of attack of the oxidizing agent is different from the case of an ionic or molecular type of reaction. In fact, as Kharasch [9] showed, in chlorinating acids the main direction of attack by the chlorination agent changes, depending on the type of reaction. In the case of an ionic mechanism, hydrogen substitution occurs mainly at the α-carbon atom while in the case of a radical one – at the β-carbon atom.

Thus, an important factor affecting the direction of the reaction is the type of mechanism by which it proceeds, together with the nature and structure of the oxidizing agent. This hypothesis is confirmed by a series of other literature data. Certain characteristics of the oxidation of acids by hydrogen peroxide are such that the reaction may be considered a radical-chain type of reaction. There is, therefore, reason to consider that the general picture of oxidation would be similar to ours. In fact, by oxidizing n-butyric acid, labeled with radiocarbon in the carboxyl and the β-CH_2 group simultaneously [2], it was shown that the direction of attack of the oxidizing agent was mainly at the β-CH_2 group.

Of course, one cannot exclude an attack by the radical particle on other carbon atoms, although this is less probable. Regrettably, the experimental data available do not permit a determination of the ratios of these directions in oxidation reactions in the total balance of acid conversions in the oxidizable hydrocarbon medium.

These peculiarities of acid oxidation may be explained from the point of view of electronic concepts. As a carboxyl is an electron-acceptor group and the oxidizing agent is electrophilic, the most convenient position for attack in the acid molecule is the β-methylene group, where the electron density is higher than in the α-position. This explains the difficulty of oxidizing acetic acid in an n-heptane medium with atmospheric oxygen. As this reaction is of a radical type and the acetic acid does not have a β-methylene group, it must be inert to the oxidizing agent – the radical.

Bearing all these considerations in mind, we may give the mechanism developed for the first stage of acid oxidation in the medium of an oxidizable hydrocarbon (R' is any radical system).

$$RCH_2CH_2COOH + R'\cdot \rightarrow R\dot{C}HCH_2COOH + R'H$$

$$R\dot{C}HCH_2COOH + O_2 \rightarrow RCH(OO\cdot)CH_2COOH$$

$$RCH(OO\cdot)CH_2COOH + R'H \rightarrow RCH(OOH)CH_2COOH + R'\cdot$$

As yet we can say nothing on the mechanism of the decomposition of hydroperoxides of this type. Only the final reaction products are known and the formation of these may be explained by the following reactions:

$$RCH(OOH)CH_2COOH \xrightarrow{-H_2O} RC(=O)CH_2COOH \rightarrow RC(=O)CH_3 + CO_2.$$

EXPERIMENTAL

We carboxylated the Grignard reagents in an apparatus described previously [5]. The acids formed were isolated and stored as the sodium salts and the free acids were prepared from these as required.

Two methods of synthesizing acids labeled in the α-CH_2 group are described in the literature [6]. We chose a slightly different method for the synthesis of n-valeric acid:

$$CH_3CH_2CH_2C^{14}OOH \xrightarrow{LiAlH_4} CH_3CH_2CH_2C^{14}H_2OH \xrightarrow{HBr} CH_3CH_2CH_2C^{14}H_2Br \xrightarrow{Mg,CO_2} CH_3CH_2CH_2C^{14}H_2COOH$$

Butyric acid, labeled in the carboxyl group, was reduced with excess lithium aluminum hydride in ether solution to give n-butyl alcohol in 60% yield [7]. The unreacted, excess lithium aluminum hydride was decomposed with water since decomposition with dilute acid involved considerable unavoidable losses during subsequent washing of the ether solution with water and soda. The ether layer was dried with sodium sulfate and, after evaporation, the n-butyl alcohol was distilled. The radioactive alcohol was converted into the bromide in 70% yield. The bromide gave an 80% yield of labeled n-valeric acid by the procedure described above. The molecular weight of the valeric acid synthesized was 104 (calculated 102). Chromatography of the labeled acid on paper showed that no other acids were present. The over-all yield on CO_2, including the preparation of carboxyl-labeled butyric acid, was 23%.

The oxidation of n-heptane with labeled acids added was performed in the apparatus described previously [8]. For the oxidation we used standard n-heptane, distilled on a column with an efficiency of 20 theoretical plates (b.p. 97.7-97.8°, n_D^{20} 1.3882). 0.02-0.197 mmoles of the appropriate acid was added per ml of n-heptane. The experiments were performed at 160° and a pressure of 6 atm, with oxygen-enriched air (60% O_2) passed through at 2 ml/min.ml. Under these conditions, a second (aqueous acid) layer appeared after two hours oxidation.

The carbon dioxide evolved was absorbed in barium hydroxide solution of known concentration. The barium carbonate precipitate was analyzed for activity. At the end of the experiment, the oxidation mixture was saponified with 1 N alkali in alcohol, then all the neutral reaction products were steam distilled from the alkaline

medium, the mixture acidified with sulfuric acid (25%) to congo red and the volatile fatty acids steam distilled off. The total amount of acid was determined by titration with limewater. The aqueous solution of calcium salts was evaporated to dryness in an atmosphere free from carbon dioxide. The amount of acid, determined in this way agreed, within the limits of error, with the total free and bound acid determined by direct titration of an oxidized sample and saponification of the esters in it. This indicated the absence of appreciable amounts of keto- and hydroxyacids and dibasic acids, which did not steam distil. The ketones were precipitated from the neutral fraction as the 2,4-dinitrophenylhydrazones. The activity of the ketones and acids was determined by the procedure published previously [8]. The neutral fraction of the oxidation products was also analyzed for methyl ketones by the iodoform reaction. The iodoform and acids formed were analyzed for activity content. After the iodoform reaction, the acids were isolated in the following way: the alkaline solution was filtered free from iodoform and acidified with sulfuric acid. The iodine liberated was bound with silver sulfate. The solution was made alkaline, the neutral products steam distilled off, the residue made acid to congo with sulfuric acid and the acids steam distilled off.

SUMMARY

1. When oxidized in the medium of an oxidizable hydrocarbon, acids undergo quantitative decarboxylation. If the carboxyl group is labeled with radiocarbon, the only active gaseous reaction product is carbon dioxide. From the activity of the carbon dioxide gas, one may determine the behavior of the carboxyl group of the acid in any complex system of hydrocarbon oxidation products.

2. The oxidizing agent attacks the acid molecule at the β-carbon atom. As a result of decarboxylation of the acid, a methyl ketone is formed with one less carbon atom than the acid.

3. The oxidizability of an acid under the given conditions depends on its molecular structure. An acid of normal structure, without a β-methylene group, is oxidized with considerably more difficulty. Acetic acid is practically inert.

4. n-Valeric acid, labeled in the α-position with radiocarbon, was prepared in 23% yield.

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THERMOCATALYTIC CONVERSIONS OF α-METHYLNAPHTHALENE

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The high-temperature decomposition of alkylnaphthalenes is of interest in connection with the study of the chemism of hydrocarbon cracking [1].

Low-temperature conversions of alkylnaphthalenes in the presence of activated clays demonstrated a series of extremely interesting reactions of this class of hydrocarbon, which are directly related to the conversions of petroleum in nature [2, 3]. These reactions were also studied using α-methylnaphthalene.

Fraction	Temperature		Weight (in g)	d_4^{20}	n_D^{20}	Molecular weight	Melting point of picrate
	boiling point	melting point					
Naphthalene	217—220°	80°	86.3	—	—	—	—
β-Methylnaphthalene	240—242	—	58.0	0.890	1.6049	140.5	113—114°
α-Methylnaphthalene	243—245	—	105.3	1.0112	1.6148	139.5	140.5
Dimethylnaphthalene	262—265	—	29.3	1.0064	1.6069	155.7	113
Dinaphthyl	190—220 (3 mm)	185.5	34.2	—	—	257	—
Residue	—	—	31.7	—	—	—	—
Coke on catalyst	—	—	37.2	—	—	—	—
Losses	—	—	18.0	—	—	—	—

400 g of the starting hydrocarbon (b.p. 244.7°, d_4^{20} 1.0112, n_D^{20} 1.6150) and an equal amount of activated clay (gumbrine) were heated in an autoclave at 350° for eight hours. The pressure reached 31 atm. At the end of the experiment, 8 m^3 of gas was collected and this had a specific gravity of 0.000723 g/cc (composition in %: CO_2 0.49, C_nH_m 0.20, O_2 1.24, CO 0.44, H_2 17.09, CH_4 76, N_2 4.54).

The liquid catalyzate, together with the catalyst, was extracted with benzene. When the solvent had been removed, the fractions shown in the Table were separated by distillation.

The percent conversion of the starting α-methylnaphthalene during the experiment was 69.2.

The β-methylnaphthalene fraction was oxidized with 5% nitric acid. The β-naphthoic acid formed was filtered off and had m.p. 180.5° after recrystallization from ether.

Thus, methane, naphthalene, β-methylnaphthalene, dimethylnaphthalene and dinaphthyl were formed during the experiment.

The formation of naphthalene and dimethylnaphthalene must be normal for these reaction conditions:

$$2C_{10}H_7CH_3 \rightarrow C_{10}H_8 + C_{10}H_6(CH_3)_2.$$

The formation of the β-isomer may be explained by its greater stability under the experimental conditions.

The result which is specific for this class of hydrocarbon is the internal hydrogenation to form methane and dinaphthyl.

The smaller amount of methane in the products of the experiment in comparison with the dinaphthyl may be explained by the reaction:

The source of hydrogen for the latter reactions may be both the heavy residues, which are impoverished in hydrogen and consist of highly condensed aromatic hydrocarbons, and hydrogen of the catalyst, introduced during its activation.

SUMMARY

1. During the conversion of α-methylnaphthalene on a natural aluminosilicate, an internal hydrogenation reaction, leading to the formation of methane and dinaphthyl was observed in addition to the simple transposition of unchanged aliphatic radicals, which is characteristic of alkylaromatic hydrocarbons.

2. The results of the experiments confirmed the mechanism of the processes of petroleum conversion in the bowels of the earth, which include, on the one hand, simplification of the composition of the petroleum material to methane and, on the other, its elaboration to form highly condensed hydrocarbons.

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SOME CONSIDERATIONS ON THE MECHANISM OF THE FORMATION OF MERCURYAROMATIC COMPOUNDS BY THE OXIDATION OF ARYLHYDRAZINES WITH MERCURIC SALTS

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A.N. Nesmeianov prepared arylmercuric chlorides by decomposing the binary compounds of aryldiazonium chloride and mercuric chloride with copper powder in organic solvents [1].

$$ArN_2Cl \cdot HgCl_2 + 2Cu \rightarrow ArHgCl + N_2 + Cu_2Cl_2$$

Later it was found [2] that when the binary salts of aryldiazonium chloride and mercuric chloride were decomposed with excess copper in the presence of ammonia, fully substituted mercuryaromatic compounds were formed.

$$2C_6H_5N_2Cl \cdot HgCl_2 + 6Cu + 6NH_3 \rightarrow (C_6H_5)_2Hg + 2N_2 + Hg + 6CuCl \cdot NH_3$$

This method was extended to the synthesis of aromatic compounds of other metals by Nesmeianov and his co-workers.

By reacting phenyldiazonium chloride with metallic mercury, Meclure [3] and Waters [4] prepared phenyl mercuric chloride

$$C_6H_5N_2Cl + Hg \rightarrow C_6H_5HgCl + N_2$$

Fischer and Ehrhard [5] isolated diphenylmercury by oxidizing phenylhydrazine with mercuric oxide in ether solution.

Seide, Scherlin and Bras [6] obtained a good yield of phenylmercuric acetate by oxidizing phenylhydrazine with mercuric acetate in an acetic acid medium in the presence of copper and its salt.

In previous papers we described a method of preparing aromatic compounds of antimony and arsenic, which consists of reacting an arylhydrazine with antimony trichloride [7], antimony pentachloride [8] and arsenic trichloride [9] in a hydrochloric acid medium in the presence of cupric chloride and atmospheric oxygen, and proposed a mechanism for this reaction [10].

In the present work, our aim was to define the mechanism of phenylmercuric acetate formation in the reaction proposed in the paper [6].

It was found that when phenylhydrazine hydrochloride was reacted with mercuric chloride in hydrochloric acid in the presence of cupric chloride, phenylmercuric chloride was formed in 43% yield (on mercuric chloride). The process of phenylmercuric chloride formation, starting from phenylhydrazine and mercuric chloride, may be represented in the following way: the mercuric chloride oxidizes the phenylhydrazine hydrochloride to phenyldiazonium chloride, which reacts with another part of the mercuric chloride to give the binary compound $C_6H_5N_2Cl \cdot HgCl_2$. The latter reacts with phenylhydrazine hydrochloride to give phenylmercuric chloride by the scheme:

$$C_6H_5NHNH_2 \cdot HCl + 4HgCl_2 \rightarrow C_6H_5N_2Cl + 2Hg_2Cl_2 + 4HCl$$

$$C_6H_5N_2Cl + HgCl_2 \rightarrow C_6H_5N_2Cl \cdot HgCl_2$$

$$2C_6H_5N_2Cl \cdot HgCl_2 + C_6H_5NHNH_2 \cdot HCl \xrightarrow{CuCl_2} 2C_6H_5HgCl + C_6H_5N_2Cl + 2N_2 + 4HCl$$

In confirmation of this scheme it was shown that when phenylhydrazine hydrochloride was reacted with the binary compound $C_6H_5N_2Cl \cdot HgCl_2$ under the conditions given above, phenylmercuric chloride was formed. Evidently an analogous scheme occurs in the formation of phenylmercuric acetate. Since phenylmercuric chloride is almost insoluble in hydrochloric acid, then it does not form a complex with phenyldiazonium chloride and, due to this, the reaction stops at the formation of phenylmercuric chloride.

EXPERIMENTAL

Reaction of phenylhydrazine hydrochloride and mercuric chloride in hydrochloric acid in the presence of cupric chloride. Phenylhydrazine hydrochloride (14.5 g) and cupric chloride (1 g) were added with stirring to a hydrochloric acid solution of mercuric chloride (27.3 g) in a jar fitted with a stirrer. At the beginning of the reaction, the color of the solution was green. After six hours stirring, the color disappeared and the suspended precipitate settled out. After 14-hours stirring, the solution again acquired a green color. The precipitate was sucked off, washed with water, alcohol and ether and dried in air. When the precipitate was recrystallized from boiling acetone with slow cooling, the acetone solution deposited lustrous scales. When the crystalline product had been washed with alcohol and ether, its weight was 13.5 g (43.1%). The product melted at 248-252°; after a second recrystallization from acetone, the product had m.p. 251-253°. A mixed melting point with phenylmercuric chloride, prepared by another method, was not depressed.

Reaction of phenylhydrazine hydrochloride with the binary compound $C_6H_5N_2Cl \cdot HgCl_2$ in hydrochloric acid in the presence of cupric chloride. A mixture of the binary compound $C_6H_5N_2Cl \cdot HgCl_2$ (30 g), phenylhydrazine hydrochloride (10 g), cupric chloride (0.5 g) and dilute hydrochloric acid (1:2) was stirred for 1.5-2 hours in a jar and the precipitate formed was separated. The reaction was accompanied by vigorous frothing (evolution of nitrogen). Two recrystallizations of the precipitate from ethyl acetate yielded 5.5 g of material (28% on the binary compound). A mixed melting point with phenylmercuric chloride was not depressed.

SUMMARY

It was shown that the reaction of phenylhydrazine hydrochloride and mercuric chloride in hydrochloric acid in the presence of cupric chloride gave phenylmercuric chloride. A reaction scheme is proposed.

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HALOGENATION OF AROMATIC SILANES

VI. PREPARATION AND PROPERTIES OF CHLORO DERIVATIVES OF p-(TRICHLOROMETHYL)PHENYLTRICHLOROSILANE

G.V. Motsarev and A.Ia. Iakubovich

We showed previously [1] that the introduction of an orientant of the first order (a methyl group) into the phenyltrichlorosilane molecule leads to activation of the aromatic nucleus and, for example, p-tolyltrichlorosilane is halogenated considerably more readily than phenyltrichlorosilane. It seemed interesting to determine the effect of introducing orientants of the second order, such as CCl_3 and CF_3 groups, into the phenyltrichlorosilane molecule on its chlorination. With this aim, we studied the chlorination of p-(trichloromethyl)phenyltrichlorosilane and p-(trifluoromethyl)phenyltrifluorosilane. The halogenation of these silanes is not described in the literature.

It is known that the CCl_3 group is a meta-orienting substituent. When $C_6H_5CCl_3$ is chlorinated in the presence of $SbCl_5$ and iodine, the meta-chloro derivative is formed predominantly [2]; nitration of $C_6H_5CCl_3$ to the mononitro derivative gives mainly the meta-nitro isomer [3]. In catalytic chlorination, in contrast to bromination, the $SiCl_3$ group in $C_6H_5SiCl_3$ also acts as a meta-orientant [4].

Considering that meta-orientants passivate the benzene nucleus in substitution reactions, one would expect that the presence of two meta-orienting substituents in the para position of p-(trichloromethyl)phenyltrichlorosilane would lead to strong deactivation of the benzene nucleus.

Actually, p-(trichloromethyl)phenyltrichlorosilane could not be chlorinated in the absence of catalyst when treated with a large excess of chlorine (molar ratio 1:22) at 190-220°.

When p-$CCl_3C_6H_4SiCl_3$ was treated with chlorine in the presence of $FeCl_3$, the reaction proceeded with difficulty at 100-110°. Depending on the molar ratio of the reagents, mono- and dichloro-substituted p-(trichloromethyl)phenyltrichlorosilanes were obtained under these conditions in yields of 68.3 and 55.4%. It was not possible to isolate a trichloro derivative from the reaction products even after treating p-$CCl_3C_6H_4SiCl_3$ with excess chlorine for a long time. In this case the main reaction product was p-(trichloromethyl)dichlorophenyltrichlorosilane. It was thus established that together with substitution, destructive chlorination occurs with the formation of $SiCl_4$ and the corresponding chloro-substituted benzotrichlorides.

The chlorination of p-(trichloromethyl)phenyltrichlorosilane may be represented by the following scheme:

$$CCl_3C_6H_4SiCl_3 \xrightarrow[-HCl]{+Cl_2} CCl_3C_6H_3ClSiCl_3 \xrightarrow[-HCl]{+Cl_2} CCl_3C_6H_2Cl_2SiCl_3 \xrightarrow{+Cl_2} CCl_3C_6H_2Cl_3 + SiCl_4$$

Cleavage of the Si–C bond by chlorine in p-$CCl_3C_6H_4SiCl_3$ proceeds more readily than in $C_6H_5SiCl_3$, but with more difficulty than in p-$CH_3C_6H_4SiCl_3$. Thus, while cleavage occurs to a very small degree in the chlorination of $C_6H_5SiCl_3$ in the presence of $FeCl_3$ only at 140-150° [5], in the case of p-$CCl_3C_6H_4SiCl_3$, this reaction occurs at 115-130° and at the same time, destructive chlorination of p-$CH_3C_6H_4SiCl_3$ is observed, even at 90 to 100° [1].

The effect of reagent ratio and temperature on the results of chlorinating p-$CCl_3C_6H_4SiCl_3$ are illustrated by the data presented in the Table.

Effect of Conditions on Product Composition in the Chlorination of p-$CCl_3C_6H_4SiCl_3$

Chlorination conditions			Composition of reaction products			Silane cleaved (in %)
amount of $FeCl_3$ (in %) of weight of silane taken)	temperature	molar ratio of silane to chlorine	unchanged silane (%)	chlorination products		
				total yield (in %)	main reaction product	
1.4	100-110°	1:4.3	12.5	68.3	Monosubstituted	–
1.7	100-110	1:8.7	–	84.4	Disubstituted	–
1.4	115-130	1:22.2	–	70.2	Disubstituted	9.2

The mono- and dichloro derivatives of p-(trichloromethyl)phenyltrichlorosilane were separated and the physicochemical data for them are given (see experimental).

To determine the structure of the monochloro derivative of p-(trichloromethyl)phenyltrichlorosilane synthesized, we planned to use cleavage of it with bromine (after preliminary exhaustive methylation [6]) and oxidation of the cleavage products with chromic acid, leading to the formation of the corresponding chlorobromo derivatives of benzoic acid.

Before using these reactions for this purpose, they were first tested by applying them to unsubstituted p-(trichloromethyl)phenyltrichlorosilane, for which the latter was first methylated using CH_3MgI.

It is known that the reaction of polyhalo derivatives of hydrocarbons with organomagnesium compounds is complicated; parallel with the exchange reaction, a side reaction often occurs in which the radicals formed combine with each other. For example, when $C_6H_5CHCl_2$ is treated with CH_3MgI, the reaction gives, exclusively, dichlorostilbene; under these conditions, $C_6H_5CCl_3$ forms tolan tetrachloride [7].

$$2C_6H_5CHCl_2 + 2CH_3MgI \rightarrow C_6H_5CHClCHClC_6H_5 + C_2H_6 + 2MgICl$$
$$2C_6H_5CCl_3 + 2CH_3MgI \rightarrow C_6H_5CCl_2CCl_2C_6H_5 + C_2H_6 + 2MgICl$$

Considering this, one would expect that the treatment of p-$CCl_3C_6H_4SiCl_3$ with CH_3MgI to prepare the corresponding aryltrimethylsilane could give as the main reaction product, 4,4'-di(trimethylsilyl)tolan tetrachloride.

$$2p\text{-}(Cl_3Si)C_6H_4CCl_3 + 8CH_3MgI \rightarrow (CH_3)_3SiC_6H_4CCl_2CCl_2C_6H_4Si(CH_3)_3 + 8MgICl + C_2H_6$$

However, experiment showed that when p-$CCl_3C_6H_4SiCl_3$ was treated with excess CH_3MgI, 4,4'-di(trimethylsilyl)tolan dichloride was formed and this was isolated in a pure state and characterized.

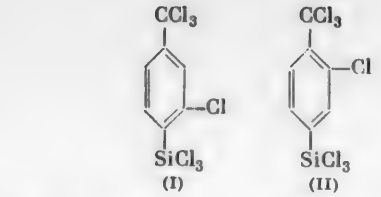
$$2p\text{-}(Cl_3Si)C_6H_4CCl_3 + 10CH_3MgI \rightarrow (CH_3)_3SiC_6H_4CCl{=}CClC_6H_4Si(CH_3)_3 + 10MgICl + 2C_2H_6$$

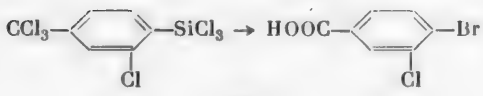
Similarly to other aryltrimethylsilanes, 4,4'-di(trimethylsilyl)tolan dichloride was readily cleaved with bromine at the $C_{arom}-Si$ bond to form $(CH_3)_3SiBr$ and 4,4'-dibromotolan dichloride, which was converted into p-bromobenzoic acid when oxidized with chromic acid.

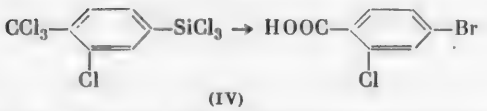
$$(CH_3)_3SiC_6H_4CCl{=}CClC_6H_4Si(CH_3)_3 + 2Br_2 \rightarrow BrC_6H_4CCl{=}CClC_6H_4Br + 2(CH_3)_3SiBr$$
$$\downarrow \xrightarrow[H_2SO_4]{+K_2Cr_2O_7} 2p\text{-}BrC_6H_4COOH$$

When a chlorine atom is introduced into p-(trichloromethyl)phenyltrichlorosilane, the two isomers (I) and (II) may be formed and cleavage of these with bromine (after preliminary exhaustive methylation), followed by oxidation of the cleavage products, could lead to the formation of 3-chloro-4-bromo- and 2-chloro-4-bromobenzoic acids (III and IV), respectively (melting points 218 and 166°, respectively).

When monochloro(p-trichloromethyl)phenyltrichlorosilane, obtained by chlorinating p-trichloromethylphenyltrichlorosilane, was treated as described above, we isolated a chlorobromobenzoic acid with m.p. 182-184°. The latter indicated that the acid was not pure and apparently was a mixture of the two possible isomeric acids (III and IV).

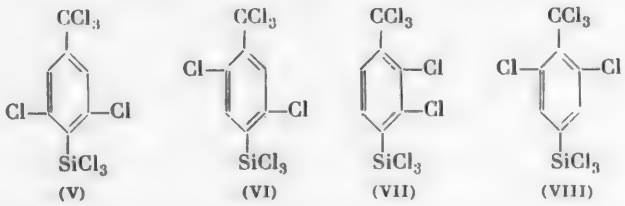






From this it follows that the monochloro(p-trichlormethyl)phenyltrichlorosilane was a mixture of the two possible isomers.

As regards the structure of the dichloro derivatives of p-trichloromethylphenyltrichlorosilane isolated, of the four possible isomers (V-VIII), the most probable structures are (V), (VI) and (VIII).



Thus, as a result of studying the reaction of p-$CCl_3C_6H_4SiCl_3$ with chlorine in the presence of $FeCl_3$, we showed that the entering chlorine atom is oriented by both of the available substituents (1-CCl_3, 4-$SiCl_3$) into positions 2 and 3.

In contrast to p-(trichloromethyl)phenyltrichlorosilane, when p-(trifluoromethyl)phenyltrifluorosilane* was treated with chlorine for a long period at its boiling point (118-119°) in the presence of $FeCl_3$ (1.7%), it was completely unchlorinated. This is apparently the result of strong deactivation of the nucleus by the CF_3 group and the relatively low chlorination temperature.

EXPERIMENTAL

Chlorination of p-trichloromethylphenyltrichlorosilane. A current of dry chlorine was passed at a rate of 20 ml/min for 6 hours 50 minutes through a porous glass plate into a mixture of 28 g of p-(trichloromethyl)phenyltrichlorosilane (m.p. 66-67°)** and 0.4 g of anhydrous $FeCl_3$ in a glass column (220 mm high and 25 mm in diameter) at 100-110°, with a layer 50 mm high in the column. The chlorination proceeded with difficulty and a large amount of chlorine passed through, unchanged. When the reaction mixture had been flushed with air, it had gained 2.6 g (compared with 3.0 g required for chlorination to the monochloro derivative). The chlorination products were distilled in vacuum (13 mm) to give: 1st fraction, b.p. 160-170°, 3.5 g, 2nd fraction, b.p. 170-182°, 24.1 g. The first fraction was mainly unchanged p-(trichloromethyl)phenyltrichlorosilane. Redistillation of the second fraction yielded 21.1 g of liquid with b.p. 171-179° (13 mm), which corresponded to monochloro(p-trichloromethyl)phenyltrichlorosilane in analysis. The yield was 68.3%, calculated on the p-(trichloromethyl)-phenyltrichlorosilane taken for reaction. The colorless, mobile liquid with a sharp smell fumed in air.

*p-$CF_3C_6H_4SiF_3$ was prepared by fluorinating p-$CCl_3C_6H_4SiCl_3$, using SbF_3 by the method described by Frost [8].
**The p-(trichloromethyl)phenyltrichlorosilane was prepared by liquid-phase, catalytic chlorination of p-tolyltrichlorosilane in the presence of azobisisobutyronitrile [9].

B.p. 172-177° (13 mm) d^{20}_{20} 1.6369, $n^{20}D$ 1.5777.

Found %: C 23.42, 23.27; H 1.03, 0.91; Cl 68.04, 68.21; Si 7.82, 7.97. $C_7H_3Cl_7Si$. Calculated %: C 23.10; H 0.82; Cl 68.36; Si 7.70.

Chlorination of p-(trichloromethyl)phenyltrichlorosilane to the dichloro derivative was carried out similarly under the same conditions, except that the amount of chlorine passed was correspondingly increased. 23 g of p-(trichloromethyl)phenyltrichlorosilane, which was chlorinated for twelve hours (4.3 g increase in weight), yielded 15.4 g of a colorless, mobile (when heated) liquid, which crystallized on cooling to give solid dichloro(p-trichloromethyl)phenyltrichlorosilane (yield 55.4%). Monochloro(p-trichloromethyl)phenyltrichlorosilane (4.5 g) was a side product. The total yield of di- and monochloro derivatives was 84.4%. The dichloro(p-trichloromethyl)phenyltrichlorosilane was a white, crystalline substance (prisms).

B.p. 189-195° (13 mm), m.p. 123-126° (from chloroform).

Found %: C 21.72, 21.61; H 0.62, 0.59; Cl 70.16, 70.94; Si 7.12, 7.21. $C_7H_2Cl_8Si$. Calculated %: C 21.10; H 0.50; Cl 71.3; Si 7.03.

In an attempt to prepare trichloro(p-trichloromethyl)phenyltrichlorosilane by chlorination of 20.9 g of p-(trichloromethyl)phenyltrichlorosilane in the presence of $FeCl_3$ (ten hours at 115-120° and 16 hours at 125-130°, chlorine rate 20 ml/min), the reaction products yielded 1.0 g of $SiCl_4$ and 17.7 g of dichloro(p-trichloromethyl)-phenyltrichlorosilane. The yield was 70.2%. When 10.6 g of p-(trichloromethyl)phenyltrichlorosilane was chlorinated in the absence of catalyst (190-200°, 13 hours and chlorine rate 20 ml/min), the reaction products yielded unchanged starting silane.

Reaction of p-trichloromethylphenyltrichlorosilane with CH_3MgI. To an ether solution of CH_3MgI, prepared from 7.2 g of magnesium, 40.2 g of CH_3I and 100 ml of absolute ether, was added a solution of 15 g of p-trichloromethylphenyltrichlorosilane in 40 ml of ether and the mixture boiled for 30 minutes on a water bath (the reaction mixture separated into two layers) and then decomposed with 5% hydrochloric acid with cooling (0°). After the usual treatment, the ether layer yielded 6.6 g of a solid substance, which corresponded in analysis to 4,4'-di(trimethylsilyl)tolan dichloride. The yield was 67%. The white crystalline substance (lustrous platelets) had m.p. 185-186° (from acetone) and was difficultly soluble in hot alcohol and cold acetone and readily soluble (at normal temperatures) in benzene and chloroform.

Found %: C 60.31, 60.95; H 7.33, 7.36; Cl 17.80, 17.90; Si 13.73, 13.60. $C_{20}H_{26}Cl_2Si_2$. Calculated %: C 61.06; H 6.6; Cl 18.06; Si 14.25.

Cleavage of 4,4'-di(trimethylsilyl)tolan dichloride with bromine. 3.5 g of bromine was added dropwise with stirring over a period of ten minutes to 4 g of 4,4'-di(trimethylsilyl)tolan dichloride. The reaction was accompanied by considerable evolution of heat (the temperature of the mixture reached 90°). When all the bromine had been added, the mixture was heated at 70-80° for 20 minutes and then 2.8 g (90.3%) of $(CH_3)_3SiBr$ with b.p. 78-80° was distilled off from it. After removal of the $(CH_3)_3SiBr$, the solid residue was recrystallized from a mixture of alcohol and acetone. We obtained 3.4 g of white crystals with m.p. 155-157°, which corresponded in analysis to 4,4'-dibromotolan dichloride. The yield was 80.2%.

Found %: C 41.63, 41.44; H 2.07, 2.01; (Cl + Br) 57.41, 57.11. $C_{14}H_8Cl_2Br_2$. Calculated %: C 41.27; H 1.96; (Cl + Br) 56.77.

Oxidation of 4,4'-dibromotolan dichloride. 3.5 ml of concentrated sulfuric acid was added over a period of ten minutes with stirring to a mixture of 2 g of 4,4'-dibromotolan dichloride, 2.5 g of $K_2Cr_2O_7$ and 5 ml of water. At this, the temperature of the mixture rose and a vigorous reaction began. When the sulfuric acid had been added and the evolution of heat ceased, the reaction mixture was boiled gently for 30 minutes. When the reaction mixture had cooled, 25 ml of water was added and the precipitate formed filtered, washed with water (until no longer acid to congo) and dissolved in 5% NaOH solution. The insoluble residue was filtered off and the filtrate poured in a thin stream with stirring into 5% sulfuric acid solution (to a weakly acid reaction). The precipitate formed was filtered off, washed first with a small amount of dilute sulfuric acid and then with water and dried. We obtained 1.34 g (68%) of white crystals with m.p. 250°, which corresponded in analysis to p-bromobenzoic acid. Literature data [10]: m.p. 250-251°.

Found %: Br 40.23, 40.46. $C_7H_5O_2Br$. Calculated %: Br 39.80.

Reaction of monochloro(p-trichloromethyl)phenyltrichlorosilane with CH_3MgI and subsequent treatment of the reaction product with bromine and chromic acid. The experiments were carried out by the procedure described in the previous sections; the intermediate reaction products were not isolated in a pure form. When 5.4 g of monochloro(p-trichloromethyl)phenyltrichlorosilane was treated with CH_3MgI, prepared from 2.65 g of Mg and 13.3 g of CH_3I in ether solution, we obtained 3.0 g of a thick, dark-yellow liquid, which was treated with 2.3 g of bromine and gave 1.5 g of $(CH_3)_3SiBr$ (b.p. 78-80°). After removal of the $(CH_3)_3SiBr$, the residual solid (3 g) was oxidized with chromic acid (4 g of $K_2Cr_2O_7$ + 5.6 ml of conc. H_2SO_4 + 6 ml of water). We obtained ~2 g of white crystals with m.p. 182-184° (from alcohol), which dissolved completely in 5% NaOH solution and corresponded in analysis to chlorobromobenzoic acid.

Found %: (Br + Cl) 49.27, 49.31. $C_7H_4O_2BrCl$. Calculated %: (Br + Cl) 49.04.

SUMMARY

1. Chlorination of $p\text{-}CCl_3C_6H_4SiCl_3$ in the presence of $FeCl_3$ gave mono- and dichloro derivatives. We were unable to obtain derivatives of $p\text{-}CCl_3C_6H_4SiCl_3$ with three and four chlorines in the nucleus (cleavage of the C–Si bond occurred).

2. It was found that the monochloro derivative of $p\text{-}CCl_3C_6H_4SiCl_3$ was a mixture of 2-chloro- and 3-chloro-4-(trichloromethyl)phenyltrichlorosilanes.

3. It was established that $p\text{-}CF_3C_6H_4SiF_3$ does not react with chlorine at its boiling point (118-119°), even in the presence of $FeCl_3$.

4. It was shown that treatment of $p\text{-}CCl_3C_6H_4SiCl_3$ with methylmagnesium iodide yielded 4,4'-di(trimethylsilyl)tolan dichloride.

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REACTION OF β-CHLOROVINYL KETONES WITH β-DICARBONYL COMPOUNDS

VII. ACID CLEAVAGE OF α-ALKYL-α-(3-KETOALKENYL)-ACETOACETIC ESTERS

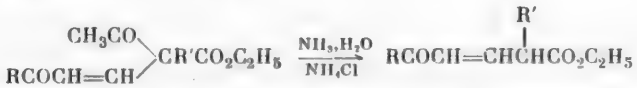
N.K. Kochetkov and B.P. Gottykh

In one of our previous works, together with L.I. Kudriashov, we were able to ketovinylate α-alkylacetoacetic esters to form α-alkyl-α-(3-ketoalkenyl)-acetoacetic esters [1]. The new class of compounds obtained is of undoubted interest for organic synthesis.

We began the investigation of the chemical behavior of α-alkyl-α-(3-ketoalkenyl)-acetoacetic esters with a study of their acid cleavage. The compounds investigated were vinylogs of α,α-diacyl derivatives of aliphatic esters, whose acid cleavage, as is known, leads to the corresponding β-ketoester of this or other structures (depending on the relative ease of elimination of the acyl groups) or a mixture of the two possible β-ketoesters. In our case we naturally expected that the acyl group would be eliminated more readily than the β-ketovinyl group.

Cleavage of α-alkyl-α-(3-ketoalkenyl)-acetoacetic esters by the most general method, i.e., treatment with concentrated alkali solutions, was impossible due to the lability of these compounds and their tendency toward complex condensations. An attempt at cleavage using catalytic amounts of sodium alcoholate by Dieckmann's method [2] gave negative results. When α-alkyl-α-(3-ketoalkenyl)-acetoacetic esters were treated with gaseous ammonia in ether solution, as recommended by Bouveault [3] for the cleavage of diacylacetic esters, the reaction was accompanied by side processes and it was only possible to isolate very small yields of analytically pure acid-cleavage products from the mixture obtained.

The use of aqueous ammonia solution containing ammonium chloride for the cleavage [4] was successful. In this case the α-alkyl-α-(3-ketoalkenyl)-acetoacetic esters underwent fairly smooth acid decomposition to form esters of α-(3-ketoalkenyl)-alkanoic acids.

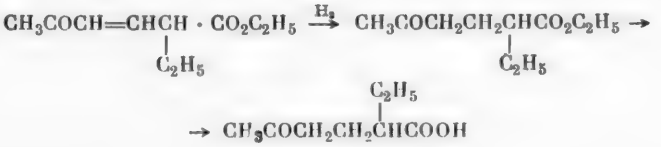


(R = CH_3, C_2H_5, C_3H_7; R′ = C_2H_5).

Detailed investigation of the reaction, using α-ethyl-α-(3-ketobutenyl)-acetoacetic ester, showed that the result depended on the amount of ammonia solution used, as is shown by the data in the Table.

As the data in the Table shows, the optimal concentration of ammonia found is also suitable for performing the reaction on a larger scale. Further investigation showed that the reaction was of a general character. On extending it to other homologs of α-alkyl-α-(3-ketoalkenyl)-acetoacetic esters, it was found that the cleavage became more difficult as the molecular weight of the compound increased and therefore the optimal ammonia concentration had to be found for each case.

The structure of the compounds we obtained was proved on the example of the simplest of them – the ester of α-(3-ketobutenyl)-butyric acid – by the scheme



Cleavage of α-Ethyl-α-(3-ketobutenyl)-acetoacetic Ester

Reagent used				Reaction temperature	Product yield (in %)
ester (in g)	NH_3 (in ml)	NH_4Cl (in g)	H_2O (ml)		
28.2	5	16	75	43-45°	25
28.2	10	16	75	46-50	48
28.2	15	16	75	49-50	70
40.0	21.5	22.6	106	47-48	69

Hydrogenation of the substance over palladium on barium sulfate gave the ester of α-ethyl-δ-ketocaproic acid, which was hydrolyzed to give the acid itself and the latter was identified as the semicarbazone.

The esters of α-(3-ketoalkenyl)-alkanoic acids obtained were vinylogs of α-alkyl-β-ketoacid esters, whose synthesis was recently achieved in our laboratory by cleavage of alkyl-(3-ketoalkenyl)-malonic esters [5]. The reaction described in the present article is a more convenient method of synthesizing them.

EXPERIMENTAL

Ethyl α-(3-ketobutenyl)-butyrate. 16 g of ammonium chloride was dissolved in 75 ml of water, 15 ml of aqueous ammonia solution (d.0.9) added, the solution heated to 45° and added to 28.2 g of α-ethyl-α-(3-ketobutenyl)-acetoacetic ester in a flask fitted with a stirrer, a thermometer and an air condenser. The reaction mixture was stirred vigorously and heated for two minutes on a water bath at 50°. The reaction proceeded with the evolution of heat and the temperature of the mixture was kept within the range 49-50°. After 40 minutes the reaction mass was cooled, the oily layer, containing the bulk of the substance, separated and the aqueous solution extracted with ether (2 x 50 ml). The ether extracts were combined with the bulk of the material, washed with dilute (1:2) hydrochloric acid (2 x 50 ml) and dried over baked magnesium sulfate. After removal of the ether, the residue was vacuum distilled and a fraction with b.p. 89-93° (1 mm) collected. After three distillations the substance had the constants:

B.p. 85-88° (1 mm), d_4^{20} 1.0058, n_D^{20} 1.4560, MR_D 49.79; calc. 49.58.

Found %: C 64.96, 64.92; H 8.78, 8.95. $C_{10}H_{16}O_3$. Calculated %: C 65.19; H 8.75.

The yellowish oil was miscible with organic solvents, insoluble in water and stable during storage. The yield was 16 g (70%).

Ethyl α-(3-ketopenten-1-yl)-butyrate was obtained similarly from 30 g of α-ethyl-α-(3-ketopenten-1-yl)-acetoacetic ester by treatment with 16 g of ammonium chloride in 75 ml of water and 25 ml of aqueous ammonia solution.

In this case the reaction mixture did not evolve heat and the temperature of the reaction mixture was kept for 40 minutes in the range 51-55°. After working up as described above, we vacuum distilled the residue, collecting a fraction with b.p. 93.5-97° (0.5 mm). After three distillations, the substance had the constants:

B.p. 88-91° (1 mm), d_4^{20} 0.9907, n_D^{20} 1.4562, MR_D 54.42; calc. 54.12.

Found %: C 66.34, 66.43; H 9.32, 9.21. $C_{11}H_{18}O_3$. Calculated %: C 66.64; H 9.15.

The yield was 15.7 g (63.5%). The yellowish oil was miscible with organic solvents, insoluble in water and stable during storage.

In a similar experiment, where the concentration of aqueous ammonia used for the cleavage was a factor of 2.5 less and corresponded to the concentration used in the previous experiment, the yield was 20%.

Ethyl α-(3-ketohexen-1-yl)-butyrate was prepared similarly from 31.8 g of α-ethyl-α-(3-ketohexen-1-yl)-acetoacetic ester by treatment with 16 g of ammonium chloride in 75 ml of water and 25 ml of aqueous ammonia solution. The temperature of the reaction mixture was kept in the range 46-48° for ten minutes. Distillation in vacuum yielded a fraction with b.p. 98-100° (1 mm).

After three distillations, the substance had the constants:

B.p. 92-94° (1 mm), d_4^{20} 0.9726, n_D^{20} 1.4561, MR_D 59.30; calc. 58.81.

Found %: C 67.85, 67.89; H 9.68, 9.61. $C_{12}H_{20}O_3$. Calculated %: C 67.89; H 9.50

The yield was 10 g (38%). The yellowish oil was miscible with organic solvents, insoluble in water and stable during storage.

In a similar experiment, where the ammonia concentration was half as great, the yield was 20%.

Ethyl α-ethyl-δ-ketocaproate. 15 g of ethyl α-(3-ketobutenyl)-butyrate was hydrogenated in 50 ml of ether over palladium on barium sulfate. Over a period of four hours, 2090 ml of hydrogen (2000 ml calculated) was consumed. Working up in the usual way gave 14 g of substance with b.p. 63-64° (0.5 mm). After a second distillation the substance had the constants:

B.p. 64-66° (1 mm), d_4^{20} 0.9671, n_D^{20} 1.5293, MR_D 49.68; calc. 50.02.

Found %: C 64.70, 64.62; H 9.83, 9.58. $C_{10}H_{18}O_3$. Calculated %: C 64.48; H 9.75.

The colorless liquid had a characteristic smell.

The semicarbazone formed colorless needles with m.p. 95.5-97° (from 30% ethyl alcohol).

Found %: N 17.47, 17.40. $C_{11}H_{21}O_3N_3$. Calculated %: N 17.27.

α-Ethyl-δ-ketocaproic acid. 9 g of ethyl α-ethyl-δ-ketocaproate was boiled for two hours with a solution of 7.7 g of sodium hydroxide in 23 ml of water. The solution was acidified with hydrochloric acid (1:2) to an acid reaction to congo and extracted with ether and the ether extracts dried over magnesium sulfate. When the solvent had been removed, the residue was vacuum distilled to give a fraction with the following constants:

B.p. 132-133° (1 mm), n_D^{20} 1.4480.

Literature data: b.p. 135-137° (2 mm) [6]; 147° (7 mm), n_D^{20} 1.4483 [5].

The yield was 5.6 g (72.5%).

The semicarbazone was prepared by the usual method.

M.p. 128-130° (from 30% ethyl alcohol).

Found %: N 19.72, 19.54. $C_9H_{17}O_3N_3$. Calculated %: N 19.52.

Literature data: m.p. 127-129° [6], 131-131.5° [5].

SUMMARY

The acid cleavage of α-alkyl-α-(3-ketoalkenyl)-acetoacetic esters was performed with aqueous ammonia solution, containing ammonium chloride. Using this reaction, we developed a general method of synthesizing α-(3-ketoalkenyl)-alkanoic esters. It was shown that with an increase in the molecular weight of the α-alkyl-α-(3-ketoalkenyl)-acetoacetic ester, the acid cleavage required more drastic conditions and gave lower yields of α-(3-ketoalkenyl)-alkanoic esters.

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INVESTIGATION IN THE ISOXAZOLE SERIES

VII. CHLOROMETHYLATION OF ISOXAZOLES

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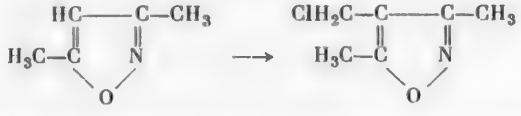
In a previous report [1] it was shown that 3-chloromethylisoxazole was a convenient starting material for the synthesis of isoxazole derivatives with various functional substituents in the side chain. In this connection it seemed of great interest to develop a general method for synthesizing other chloromethylisoxazoles and the most suitable method appeared to be the chloromethylation reaction. Despite the fact that this method is applied very widely in the aromatic series, information on the chloromethylation of heterocyclic compounds is extremely scanty and is limited to data on the chloromethylation of some thiophenes [2-4] and esters of pyromucic acid [5, 6]. No information has been published up to now on the chloromethylation of nitrogen-containing heterocyclic compounds, including isoxazoles. An investigation of the chloromethylation of isoxazoles is also of fundamental interest in broadening our knowledge of this interesting heterocyclic system, for which the only electrophilic substitution reactions known are separate, haphazard examples of halogenation [7], nitration [8] and sulfonation [9].

In our laboratory it was recently shown that 3,5-dimethylisoxazole will undergo chloromethylation [10]. In the present report we present data from a detailed study of this reaction for various substituted isoxazoles. We first made a detailed study of chloromethylation conditions using the readily available 3,5-dimethylisoxazole so as to select the most advantageous procedure for chloromethylation in the isoxazole series. The choice of this example was also dictated by the fact that in this case isomer formation was excluded.



3,5-Dimethylisoxazole was chloromethylated with various agents (paraformaldehyde with hydrogen chloride, dichlorodimethyl ether and monochlorodimethyl ether), using various catalysts (zinc chloride, sulfuric acid and stannic chloride) and in various solvents (hydrochloric acid, sulfuric acid, dichloroethane, chloroform and excess chlorodimethyl ether). The results obtained in studying this reaction are presented in Table 1.

As the data in Table 1 show, the result of the reaction depended to a considerable degree on the nature of the chloromethylating agent, the catalyst and the reaction conditions. In most cases a considerable part of the original 3,5-dimethylisoxazole was recovered unchanged (experiments 1, 4 and 7-11). When the reaction temperature was raised to 70-75° or the heating time was increased, there was considerable tar production in the reaction mixture; the yield of chloromethyl derivative was not thus increased, but the original 3,5-dimethylisoxazole could not be recovered from the reaction mixture. The optimal conditions, which we also used in further work, were chloromethylation with paraformaldehyde and hydrogen chloride (experiment 1) in dichloroethane (yield on dimethylisoxazole used, about 30% and 40-45% on that which reacted). Chloromethylation with dichlorodimethyl ether (experiment 4) gave approximately the same results, but this method was less convenient as regards starting materials. The most suitable catalyst was zinc chloride. Sulfuric acid was too drastic and, on the other hand, stannic chloride was too mild a catalyst. The reaction was best performed in dichloroethane or chloroform and the use of excess chloro- or dichlorodimethyl ether as the solvent was not advantageous.

TABLE 1

Chloromethylation of 3,5-Dimethylisoxazole

Expt. No.	Chloromethylating agent	Catalyst	Medium	Reaction conditions	Yield (in %) on dimethylisoxazole used	Yield (in %) on dimethylisoxazole reacted	Comments
1	Paraformaldehyde – HCl	$ZnCl_2$	Dichloroethane	HCl passed for 1.5 hours at 55-60°, boiled for 3 hours	30	46	35% dimethyl isoxazole recovered. Insignificant tar formation
2	Paraformaldehyde – HCl	$ZnCl_2$	"	HCl passed for 3 hours at 75°, boiled for 5 hours	26	26	No dimethylisoxazole recovered. Strong tar formation
3	Paraformaldehyde – HCl	$ZnCl_2$	Conc. HCl	Heating for 12 hours at 68-72°	23	25	8% dimethylisoxazole recovered. Strong tar formation
4	CH_2ClOCH_2Cl	$ZnCl_2$	Chloroform	Boiling for 12 hours	29	48	40% dimethylisoxazole recovered. Insignificant tar formation
5	CH_2ClOCH_2Cl	$ZnCl_2$	Dichloroethane	Boiling for 14 hours	30	30	No dimethylisoxazole recovered. Strong tar formation
6	CH_2ClOCH_2Cl	$ZnCl_2$	Excess CH_2ClOCH_2Cl	Heating at 50-60° for 14 hours	20	24	15% dimethylisoxazole recovered. Strong tar formation
7	CH_2ClOCH_2Cl	$SnCl_4$	Chloroform	Boiling for 6 hours	12	18.5	35% dimethyl isoxazole recovered. Insignificant tar formation
8	CH_2ClOCH_2Cl	Conc. H_2SO_4	Conc. H_2SO_4	Heating at 70-80° for 4 hours	0	0	45% dimethylisoxazole recovered. Strong tar formation
9	CH_2ClOCH_3	$ZnCl_2$	Excess CH_2ClOCH_3	Heating at 60° for 12 hours	21	33	37% dimethylisoxazole recovered. Considerable tar formation
10	CH_2ClOCH_3	$ZnCl_2$	The same	Boiling for 18 hours	12	18.5	35% dimethylisoxazole recovered. Strong tar formation
11	CH_2ClOCH_3	$ZnCl_2$	"	Boiling for 12 hours	2.5	3.5	20% dimethylisoxazole recovered. Strong tar formation.

Under the established optimal conditions (experiments 1 and 4), the chloromethylation of 3,5-dimethylisoxazole proceeded extremely smoothly and gave steady yields; the reaction product was isolated by the usual methods. We also attempted to establish the composition of the tarry residue, obtained in different amounts during chloromethylation under various conditions. By distillation we were able to isolate a very small amount of a substance with m.p. 72-74°, which differed, however, in analysis from bis-(3,5-dimethylisoxazolyl)-methane, whose formation could be expected; evidently, it was a more complex polycondensation product.

In order to widen the application of this reaction and to study the effect of alkyl substituents on the result of chloromethylation, we then studied the chloromethylation of 3- and 5-methylisoxazoles, isoxazole itself and also 5-phenylisoxazole under the optimal conditions. The experimental results are given in Table 2.

TABLE 2

Chloromethylation of Isoxazole and Its Homologs

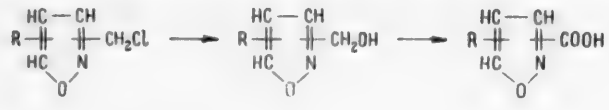
Expt. No.	Starting compound	Solvent	Reaction conditions	Yield (in % of isoxazole taken)
1	3,5-Dimethylisoxazole	Dichloroethane	HCl passed for 2 hours at 52°, boiling for 3 hours	30
2	5-Methylisoxazole	"	HCl passed for 2 hours at 60°, boiling for 3 hours	26
3	3-Methylisoxazole	"	HCl passed for 3 hours at 60°, boiling for 4 hours	19.5
4	Isoxazole	Chloroform	HCl passed for 8 hours at boiling point, boiling for 8 hours	1.8

The results obtained indicate very clearly that the yield of chloromethylation product fell with a decrease in the number of substituent methyl groups in the isoxazole nucleus. With isoxazole itself, the chloromethylation proceeded to the least extent and despite many attempts and variations in the conditions, we were unable to change the result and to isolate the chloromethylation product in an analytically pure state.

Thus, as in the aromatic series, chloromethylation in a heterocyclic ring is facilitated by the presence of a substituent of the first order in the nucleus and, consequently, it obeys the law of electrophilic substitution in the isoxazole series. This further confirms the fact that the isoxazole system represents a typical aromatic system here. At the same time we should note that under the same conditions, the aromatic analogs of the compounds we used (benzene, toluene and xylene) are chloromethylated much more readily, which indicates the relative inertness of the isoxazole ring in electrophilic substitution reactions, which in this connection exceeds not only such "superaromatic" heterocycles as pyrrole, thiophene and furan, but also benzene.

In contrast to 3,5-dimethylisoxazole, chloromethylation of 3- and 5-methylisoxazoles can lead to the formation of one or another isomer or a mixture of both possible isomers. Investigation showed that chloromethylation of both 3-methylisoxazole and 5-methylisoxazole gave only one reaction product; thus, the chloromethylation reaction goes practically in one direction. Thus, the reaction mixture obtained by the chloromethylation of 5-methylisoxazole, was distilled on a vacuum column and 90% of it came over in a range of 0.1-0.2°. The very small amount of light fraction possibly contained some impurities, whose presence should not be explained by the chloromethylation proceeding in more than one direction, but by the presence of traces of isomers in the starting 3- and 5-methylisoxazoles, as the method of preparing them [12, 13] did not exclude the presence of a few percent of other isomers in them.

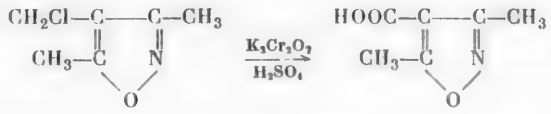
To solve the problem of the structure of the chloromethyl derivatives obtained, we developed a method of converting them into the corresponding isoxazolyl carbinols and then into the isoxazolecarboxylic acids by the scheme



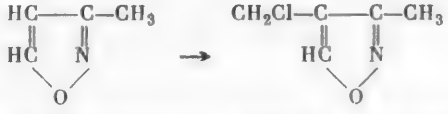
Hydrolysis of chloromethyl derivatives of the isoxazole series into the corresponding alcohols involves difficulties as the isoxazole ring is readily opened by treatment with substances of an alkaline character. One of us and A.Ia. Khorlin attempted to prepare 3-hydroxymethylisoxazole from the corresponding chloride through the acetate [11]. Although the acetate was obtained in high yield, it could not be hydrolyzed.

We have now devised conditions for the direct hydrolysis of chloromethyl derivatives into the corresponding hydroxymethylisoxazoles by heating the chlorides with an aqueous suspension of freshly precipitated lead oxide. By this method, the alcohols were obtained in high yields (60-70%) and the reaction put forward is a new and preparatively-convenient method of obtaining hydroxymethylisoxazoles, which, up to now, could only be obtained through the corresponding difficultly accessible aminomethylisoxazoles [13]. Considering the availability of chloromethylisoxazoles by direct chloromethylation, the method of synthesizing hydroxymethylisoxazoles that we proposed is quite obviously preferable.

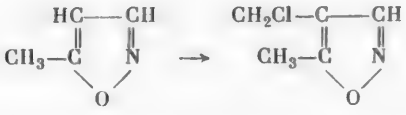
Oxidation of the hydroxymethylisoxazoles obtained to the corresponding acids did not present difficulties and was performed by a known method [13], using chromic mixture. The isoxazolecarboxylic acids were thus obtained in high yields. The isoxazolecarboxylic acids could be obtained by direct oxidation of the chloromethyl derivatives with chromic mixture, by-passing the corresponding carbinols, and this has preparative value; we used this method to prepare 3,5-dimethylisoxazole-4-carboxylic acid and to prove the structure of the chloromethylation product of 5-phenylisoxazole (see below).



When the chloromethylation product of 3-methylisoxazole was hydrolyzed, we obtained a liquid 3-methyl-hydroxymethylisoxazole, whose p-nitrobenzoate had m.p. 130-132°. This constant differed sharply from the constant of the p-nitrobenzoate of 3-methyl-5-hydroxymethylisoxazole (m.p. 82-83° [13]), whose formation would be expected. Oxidation of the alcohol obtained gave, as the sole reaction product, a 3-methylisoxazolecarboxylic acid with m.p. 121-122°, while 3-methylisoxazole-5-carboxylic acid has m.p. 210-211° [13, 14]. Thus, we were obviously dealing with 3-methylisoxazole-4-carboxylic acid and 3-methyl-4-hydroxymethylisoxazole, which are not described in the literature, and, consequently, the chloromethylation product of 3-methylisoxazole was 3-methyl-4-chloromethylisoxazole.



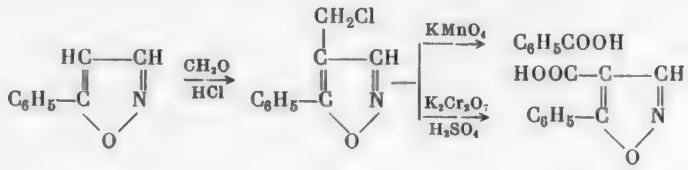
Exactly the same hydrolysis of the chloromethylation product of 5-methylisoxazole gave, as the sole reaction product, a hydroxymethylisoxazole, whose p-nitrobenzoate had m.p. 125-126° and oxidation of the alcohol gave only an acid with m.p. 146-147°. The two substances differed sharply in constants from the p-nitrobenzoate of 5-methyl-3-hydroxymethylisoxazole and 5-methylisoxazole-3-carboxylic acid (m.p. 92-93° [13] and 176-177° [13, 14], respectively). Consequently, the compounds we obtained were 5-methyl-4-hydroxymethylisoxazole and 5-methylisoxazole-4-carboxylic acid, respectively, which are not described in the literature.



To prove the absence of traces of isomeric chloromethyl derivatives in the chloromethylation reaction product, we investigated the small, most volatile fraction, obtained on distilling the chloromethylation product of 5-methylisoxazole on a column (see above). Without any purification, the latter was treated with the silver salt of p-nitrobenzoic acid. The p-nitrobenzoate of isomeric 5-methyl-3-hydroxymethylisoxazole could not be isolated from the mixture of p-nitrobenzoates of isoxazolylcarbinols thus obtained.

The insufficiency of the amount of chloromethylation product from isoxazole itself and the difficulties arising in its purification, prevented us from determining the structure of this substance similarly; however, there can be hardly any doubt that it was 4-chloromethylisoxazole. We have now proved definitely that nitration of isoxazole occurs at position 4, confirming this proposal. Data on the nitration will be published in the next communication.

On chloromethylating 5-phenylisoxazole with paraformaldehyde and hydrogen chloride in dichloroethane in the presence of zinc chloride, we obtained a solid chloromethyl derivative in 37% yield. Oxidation of the latter with potassium permanganate gave a high yield of benzoic acid; phthalic acids were not detected in the oxidation products. Hence it follows that chloromethylation of 5-phenylisoxazole proceeded exclusively in the isoxazole ring and did not involve the phenyl group in the least. To determine the position in which the chloromethyl group was introduced, we attempted to carry out the conversions in the scheme described previously for the methylisoxazoles. However, hydrolysis of 5-phenylchloromethylisoxazole gave an oily mixture of products. As a result, we used the direct oxidation of the chloromethyl derivative with chromic mixture, which gave about 70% yield of an acid with m.p. 148-149°, which was close in its properties to 5-phenylisoxazole-4-carboxylic acid, which is described in the literature. The conversions described can be represented by the following scheme.



From the material presented it is obvious that chloromethylation of 5-phenylisoxazole proceeded in position 4 of the isoxazole nucleus. This confirms data from one of our previous reports [15] that electrophilic substitution in 5-phenylisoxazole occurs at position 4. Thus, in the 5-phenylisoxazole system the isoxazole nucleus is more active than the phenyl, with the latter very clearly showing an activating effect. Thus, for example, isoxazole itself is only chloromethylated to a low degree (yield, 1.8%), but with phenylisoxazole the yield is 37%. Moreover, the phenyl nucleus activates the isoxazole ring more strongly than methyl groups, as is shown by the yields of chloromethyl derivatives (37, 26 and 19%, respectively), obtained under the same conditions.

From the data presented, it is obvious that chloromethylation of substituted isoxazoles proceeds only in position 4 (regardless of the position of other substituents), when this position in the nucleus is free, and consequently, position 4 is the most active one in the isoxazole nucleus.

EXPERIMENTAL

4-Chloromethyl-3,5-dimethylisoxazole. a) For 1.5-2 hours a fast stream of hydrogen chloride was passed into a vigorously stirred mixture of 20 g of dimethylisoxazole, 8 g of paraformaldehyde, 10 g of anhydrous zinc chloride and 50 ml of dichloroethane at 50-55°. The mixture was then boiled for three hours and poured into water, the dichloroethane layer separated, the aqueous layer carefully neutralized with potash, extracted with chloroform and then saturated with potash, the zinc hydroxide removed by filtration and the aqueous layer again extracted with chloroform. The combined extracts were washed with sodium bicarbonate solution and water and dried over calcium chloride. The solvent was evaporated and the residue vacuum distilled to give 11 g of the original 3,5-dimethylisoxazole with b.p. 30-40° (7 mm) and 9 g of 4-chloromethyl-3,5-dimethylisoxazole (30% calculated on the dimethylisoxazole taken and 46% on that which reacted) with b.p. 88-90% (7 mm). Distillation of the tarry residue yielded a fraction with b.p. 90-150° (7 mm), which, on standing, deposited a small amount of a crystalline substance with m.p. 73-74° (from benzine).

b) Heating a mixture of 25 g of 3,5-dimethylisoxazole and 15 g of paraformaldehyde in 130 ml of concentrated hydrochloric acid at 68-72° for 12 hours, treating the mixture with sodium hydroxide solution, extracting with benzene and working up in the usual way yielded 8.5 g of 4-chloromethyl-3,5-dimethylisoxazole (23%) and 2 g of starting dimethylisoxazole.

c) A mixture of 15 g of 3,5-dimethylisoxazole, 25 g of dichlorodimethyl ether, 8 g of anhydrous zinc chloride, 1 ml of water and 40 ml of chloroform was boiled for 12 hours with vigorous stirring. The mixture was

poured into water, the chloroform layer separated and the aqueous layer neutralized with bicarbonate solution and extracted with chloroform. The combined extracts were treated as described above and yielded 6.5 g of 4-chloromethyl-3,5-dimethylisoxazole (29 and 48%, respectively, on the dimethylisoxazole taken and consumed) with b.p. 88-90° (7 mm) and 6 g of starting dimethylisoxazole.

The chloromethylation with monochloromethyl ether was performed under analogous conditions. The conditions of the other chloromethylation experiments, which are not of preparative interest, are shown by the data in Table 1. After redistillation, the 4-chloromethyl-3,5-dimethylisoxazole had the constants:

B.p. 67-67.5° (1 mm), n_D^{20} 1.4852, d_4^{20} 1.1738, MR_D 5.55; calc. 35.49.*

Found %: Cl 24.63, 24.66. C_6H_8ONCl. Calculated %: Cl 24.36.

The colorless oil was lachrymatory, difficultly soluble in water and stable during storage.

3-Methyl-4-chloromethylisoxazole. This was prepared by the method a described above from 34 g of 3-methylisoxazole [11], 18 g of paraformaldehyde and 21 g of zinc chloride in 100 ml of dichloroethane. The hydrogen chloride was passed for three hours at 60-65° and the mixture boiled for three hours. Distillation yielded 13 g (37%) of original 3-methylisoxazole with b.p. 35-50° (50 mm) and 10 g (19.5%) of the chloromethylation product with b.p. 71-81° (9 mm).

B.p. 61-62° (1 mm), n_D^{20} 1.4874, d_4^{20} 1.2026, MR_D 31.49; calc. 31.00.

Found %: Cl 26.71, 26.84. C_5H_6ONCl. Calculated %: Cl 26.99.

3-Methyl-4-chloromethylisoxazole was a colorless mobile liquid, soluble in ether, chloroform and alcohol and lachrymatory.

5-Methyl-4-chloromethylisoxazole. This was prepared by method a from 37 g of 5-methylisoxazole [12], 20 g of paraformaldehyde, 24 g of zinc chloride in 100 ml of dichloroethane. The hydrogen chloride was passed for 3.5 hours at 60-70° and the reaction mixture boiled for four hours. Distillation yielded 9 g (24%) of original 5-methylisoxazole with b.p. 35-40° (40 mm) and 17 g (29% on the 5-methylisoxazole taken and 39% on that reacted) of chloromethylation product with b.p. 78-80° (9 mm). Distillation on a vacuum column of 12 theoretical plates yielded 0.8 g of a fraction with b.p. 74-78° (6 mm) and 12 g of the main fraction.

B.p. 78° (6 mm), n_D^{20} 1.4883, d_4^{20} 1.2028, MR_D 31.54; calc. 31.00.

Found %: Cl 26.74, 26.76. C_5H_6ONCl. Calculated %: Cl 26.99.

5-Methyl-4-chloromethylisoxazole was a colorless, mobile, lachrymatory liquid; it dissolved in ether, chloroform and alcohol. It darkened on prolonged storage.

4-Chloromethylisoxazole was obtained from 27 g of isoxazole [16], 17 g of paraformaldehyde, 20 g of zinc chloride in 120 ml of chloroform by method a. The hydrogen chloride was passed for eight hours with the reaction mixture boiling, then the latter was boiled for eight hours. The solvent was removed using an efficient fractionating column; the residue was vacuum distilled twice. The yield was 0.8 g (1.8%). The b.p. was 63-64° (5 mm), n_D^{20} 1.4742, d_4^{20} 1.2337. 4-Chloromethylisoxazole was a colorless, mobile liquid, which readily dissolved in ether, alcohol, chloroform and benzene; it was weakly lachrymatory and yellowed on standing.

5-Phenyl-4-chloromethylisoxazole was prepared by method a from 28 g of 5-phenylisoxazole [17], 9 g of paraformaldehyde and 10 g of zinc chloride in 150 ml of dichloroethane. The hydrogen chloride was passed for 2.5 hours at 60-65° and then the reaction mixture boiled for 3.5 hours. The solvent was removed and the residue heated on a boiling water bath at 15 mm for one hour and then left for 10-12 hours at 10-15°. The colorless crystals formed were filtered off. The mother liquors consisted of 5-phenylisoxazole and a small amount of chloromethyl derivative dissolved in it, which could be partially isolated by freezing out. We isolated 16 g (57%) of the original 5-phenylisoxazole and 11.5 g (37% calculated on the phenylisoxazole used in the reaction) of product with m.p. 51-52° (from alcohol).

Found %: Cl 18.63, 18.42. $C_{10}H_8ONCl$. Calculated %: Cl 18.30.

*In calculating the MR_D, the ring-nitrogen increment was taken as 2.84, as in all work in this series.

5-Phenyl-4-chloromethylisoxazole was a colorless, crystalline substance, which was readily soluble in ether and benzene, more difficultly so in alcohol and insoluble in water.

3,5-Dimethyl-4-hydroxymethylisoxazole. A mixture of 14.5 g of 3,5-dimethyl-4-chloromethylisoxazole and 38 g of freshly precipitated lead oxide in 100 ml of water was boiled with stirring for three hours. The precipitate was filtered off, the filtrate extracted with ether in an extractor and the ether extracts dried over sodium sulfate and evaporated in vacuum without heating. The crystals formed were filtered off and recrystallized from ether, when they had m.p. 73-74°. The yield was 8.5 g (67%).

Found %: C 56.80, 56.94; H 7.45, 7.39. $C_6H_9O_2N$. Calculated %: C 56.68; H 7.13.

3,5-Dimethyl-4-hydroxymethylisoxazole formed colorless crystals, which were readily soluble in water and alcohol.

5-Methyl-4-hydroxymethylisoxazole was prepared similarly to the above from 12 g of 5-methyl-4-chloromethylisoxazole (isolated after distillation on a column) and 26 g of freshly precipitated lead oxide. After evaporation of the ether, the residue was vacuum distilled twice. The yield was 6.3 g (60%).

B.p. 109° (3 mm), n_D^{20} 1.4835, d_4^{20} 1.1958, MR_D 27.04; calc. 27.53.

Found %: C 53.41, 53.64; H 6.52, 6.52. $C_5H_7O_2N$. Calculated %: C 53.09; H 6.24.

5-Methyl-4-hydroxymethylisoxazole was a colorless, viscous liquid with a mintlike smell. It was readily soluble in water, alcohol and ether.

The p-nitrobenzoate was prepared from 0.55 g of 5-methyl-4-hydroxymethylisoxazole and 1.0 g of p-nitrobenzoyl chloride, dissolved in pyridine, which was heated on a boiling water bath for 20 minutes; the cooled reaction mixture was poured into water. The crystals formed were filtered off and washed with sodium hydroxide solution. After recrystallization from benzine (90-100°), the substance had m.p. 125-126°.

Found %: C 55.21, 55.18; H 3.90, 3.95. $C_{12}H_{10}O_5N_2$. Calculated %: C 54.96; H 3.81.

3-Methyl-4-hydroxymethylisoxazole. This was prepared as described above from 8.5 g of 3-methyl-4-chloromethylisoxazole and 18 g of freshly precipitated lead oxide. After two distillations, we obtained 5.1 g (70%) of material.

B.p. 100-101° (1 mm), n_D^{20} 1.4839, d_4^{20} 1.1956, MR_D 27.09; calc. 27.53.

Found %: C 52.81, 52.94; H 6.35, 6.40. $C_5H_7O_2N$. Calculated %: C 53.09; H 6.24.

3-Methyl-4-hydroxymethylisoxazole was a viscous, colorless liquid with a spicy smell and was readily soluble in water, alcohol and ether. The p-nitrobenzoate was obtained similarly to the p-nitrobenzoate of 5-methyl-4-hydroxymethylisoxazole, described above. The m.p. was 130-132° (from benzine).

Found %: C 54.90, 54.78; H 3.70, 3.75. $C_{12}H_{10}O_5N_2$. Calculated %: C 54.96; H 3.81.

3,5-Dimethylisoxazole-4-carboxylic acid. A. 20 ml of concentrated sulfuric acid was added dropwise to a mixture of 3.5 g of 3,5-dimethyl-4-hydroxymethylisoxazole and 10 g of potassium bichromate in 30 ml of water. The mixture was heated for one hour on a boiling water bath, 5 g of ammonium sulfate added and the whole shaken. The colorless crystals which precipitated were filtered off and washed with dilute hydrochloric acid. The yield was 3 g. The filtrate was extracted with ether and the ether evaporated without heating. We obtained an extra 0.2 g of substance. The total yield was 3.2 g (82%). After recrystallization from water and benzene, the material had m.p. 141-142°.

Found %: C 51.38, 51.24; H 5.17, 5.10. $C_6H_7O_3N$. Calculated %: C 51.06; H 5.00.

3,5-Dimethylisoxazole-4-carboxylic acid was a colorless, crystalline substance, which was readily soluble in ether and alcohol.

B. 50 ml of concentrated sulfuric acid was added dropwise to a mixture of 7 g of 3,5-dimethyl-4-chloromethylisoxazole and 30 g of potassium bichromate in 100 ml of water, the mixture heated up and boiled. When the boiling ceased, 15 g of ammonium sulfate was added. The crystals, which precipitated after cooling, were filtered off and washed with 10% hydrochloric acid. The yield was 5 g (73%). After recrystallization from water, the substance had m.p. 141-142°. A mixed melting point with the sample prepared by method A was not depressed.

5-Methylisoxazole-4-carboxylic acid. This was prepared by method A, described for 3,5-dimethylisoxazole-4-carboxylic acid, from 1.6 g of 5-methyl-4-hydroxymethylisoxazole, 5 g of potassium bichromate in 20 ml of water and 12 ml of sulfuric acid. The yield was 1.7 g (94%). After recrystallization from water, the substance had m.p. 146-147°.

Found %: C 47.00, 46.74; H 4.07, 3.99. $C_5H_5O_3N$. Calculated %: C 47.24; H 3.88.

5-Methylisoxazole-4-carboxylic acid formed colorless crystals, which were readily soluble in ether and chloroform.

3-Methylisoxazole-4-carboxylic acid. This was prepared similarly by method A from 2 g of 3-methyl-4-hydroxymethylisoxazole, 7 g of potassium bichromate in 25 ml of water and 15 ml of sulfuric acid. The yield was 2.2 g (99%). After recrystallization from water and benzene, the substance had m.p. 121-122°.

Found %: C 47.44, 47.25; H 4.12, 4.00. $C_5H_5O_3N$. Calculated %: C 47.24; H 3.88.

3-Methylisoxazole-4-carboxylic acid was a colorless, crystalline substance, which was soluble in alcohol and ether.

5-Phenylisoxazole-4-carboxylic acid. This was prepared by method B, described for 3,5-dimethylisoxazole-4-carboxylic acid, from 0.75 g of 5-phenyl-4-chloromethylisoxazole, 1.7 g of potassium bichromate in 15 ml of water and 5 ml of sulfuric acid. The substance was recrystallized from water and benzene. The m.p. was 148 to 149°. The yield was 0.5 g (68%).

Found %: C 63.26; H 3.85. $C_{10}H_7O_3N$. Calculated %: C 63.49; H 3.73.

5-Phenylisoxazole-4-carboxylic acid was a colorless, crystalline substance, which was readily soluble in alcohol and ether. According to literature data [18], the m.p. is 155-156°.

The filtrate and mother liquors from recrystallization did not contain other isomeric phenylisoxazolecarboxylic acids.

Oxidation of 5-phenyl-4-chloromethylisoxazole with potassium permanganate. A mixture of 1.0 g of 5-phenyl-4-chloromethylisoxazole and 6.5 g of potassium permanganate in 50 ml of water was boiled for six hours. The manganese dioxide formed was filtered off and the filtrate cooled, evaporated to small volume and acidified with hydrochloric acid. The acid liberated was filtered off to give colorless crystals with m.p. 121-121.5° (from water). The yield was 0.4 g (65%). A mixed melting point with an authentic sample of benzoic acid was not depressed. Other reaction products could not be detected in the mother liquors from the recrystallization. Oxidation of the mother liquor, left after separation of the 5-phenyl-4-chloromethylisoxazole from the chloromethylation reaction (see above), was performed similarly and yielded benzoic acid (yield 80%) with m.p. 121-122°.

SUMMARY

1. A method of synthesizing chloromethylisoxazoles by chloromethylating the corresponding isoxazoles was developed. It was shown that the best results were obtained by chloromethylation with paraformaldehyde and hydrogen chloride in the presence of zinc chloride in dichloroethane and chloromethylation with dichlorodimethyl ether.

2. It was shown that the ease of chloromethylation in the isoxazole series increased with an increase in the number of methyl groups in the nucleus.

3. It was shown that in all cases when position 4 in the isoxazole nucleus was not substituted, the chloromethylation reaction occurred at this position. This was also true for 5-phenylisoxazole.

4. A method was developed for hydrolyzing chloromethylisoxazoles into the corresponding alcohols by heating the chlorides with an aqueous suspension of lead oxide.

5. A method was developed for direct oxidation of substituted chloromethylisoxazoles into the corresponding isoxazolecarboxylic acids.

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HETEROCYCLIC COMPOUNDS

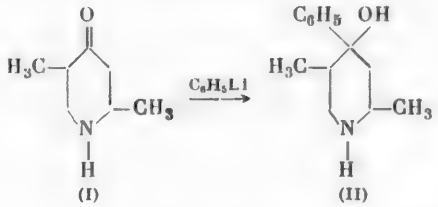
63. SYNTHETIC ANALGESICS. XXVI. STEREOISOMERISM OF 2,5-DIMETHYL-4-PIPERIDOLS AND 1-ACYL-2,5-DIMETHYL-4-PHENYL-4-PIPERIDOLS

I.N. Nazarov,* N.S. Prostakov and N.N. Mikheeva

Continuing our investigations in the series of 1-alkyl-2,5-dimethyl-4-aryl-4-piperidols and their esters, in which class promedol, isopromedol and α-promedol belong [1], we synthesized the analogs of these piperidine alcohols in which an acyl radical was substituted on the nitrogen.

We also synthesized the stereoisomeric 2,5-dimethyl-4-phenyl-4-piperidols and were able to convert them to the earlier described stereoisomeric 1,2,5-trimethyl-4-phenyl-piperidols [1].

We obtained 2,5-dimethyl-4-phenyl-4-piperidol (II) in 40% yield by reacting phenyllithium with 2,5-dimethyl-4-piperidone (I).



(I) (II)

Of the four theoretically possible stereoisomers of 2,5-dimethyl-4-phenyl-4-piperidol (II) we isolated the γ-isomer and the α-isomer in crystalline form. The third isomer of piperidol (II), formed in the indicated reaction, was isolated as the N-acetyl derivative, described below.

We used chromatography on aluminum oxide and recrystallization to separate the mixed stereoisomeric 2,5-dimethyl-4-phenyl-4-piperidole.

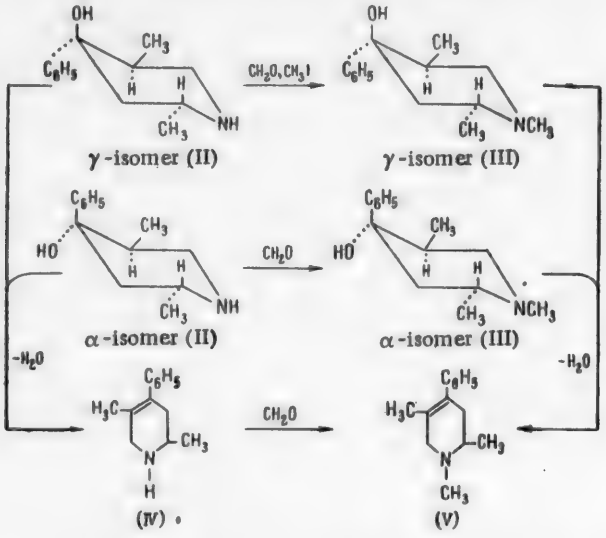
The low-melting γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II) constituted approximately 85-90% of the total mixture of crystalline isomers. When methylated with either formaldehyde or methyl iodide it was converted to the γ-isomer of 1,2,5-trimethyl-4-phenyl-4-piperidol (III), which is also obtained as the main product when phenyllithium is reacted with 1,2,5-trimethyl-4-piperidone [1].

The methylation of the α-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II) gave the α-isomer of piperidol (III).

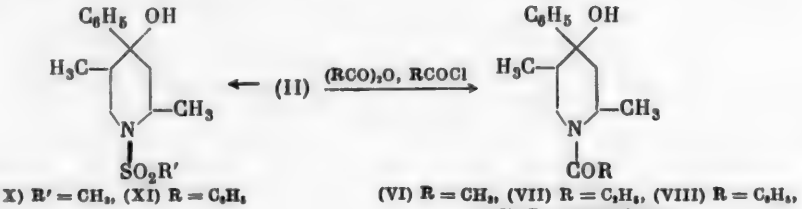
In the present paper we also used chromatography to separate the mixed stereoisomeric 1,2,5-trimethyl-4-phenyl-4-piperidole (III). Here it was found that aluminum oxide displays a different adsorption capacity toward the stereoisomeric piperidols (II) and (III). For both 1,2,5-trimethyl-4-phenyl-4-piperidol and 2,5-dimethyl-4-phenyl-4-piperidol the stereoisomeric alcohols, adsorbed by aluminum oxide, are eluted by chloroform in the following order: γ, β-, and then the α-isomer (the β-isomer was isolated in the case of separating the mixed stereoisomeric 1,2,5-trimethyl-4-phenyl-4-piperidols).

*Deceased.

The γ- and α-isomers of 2,5-dimethyl-4-phenyl-4-piperidol (II) when dehydrated with 70% sulfuric acid give the same product, namely 2,5-dimethyl-4-phenyl-1,2,3,6-tetrahydropyridine (IV), which on methylation is converted to 1,2,5-trimethyl-4-phenyl-1,2,3,6-tetrahydropyridine (V). The latter is also formed when either the γ- or the α-isomer of 1,2,5-trimethyl-4-phenyl-4-piperidol (III) is dehydrated.



The acylation of the 2,5-dimethyl-4-phenyl-4-piperidols (II) with either acid anhydrides or acid chlorides readily gave the corresponding N-acyl derivatives:

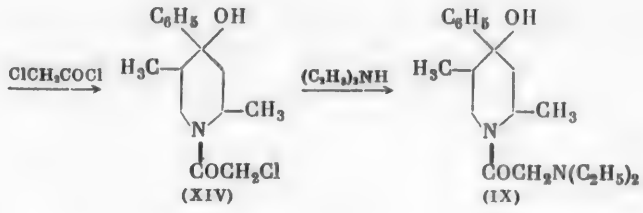


In this manner we obtained the following in yields up to 85%: (VI) 1-acetyl-, (VII) 1-propionyl-, (VIII) 1-benzoyl-, (IX) 1-diethylaminoacetyl-, (X) 1-methylsulfonyl- and (XI) 1-benzenesulfonyl-2,5-dimethyl-4-phenyl-4-piperidol.

The acetylation of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II) gave the γ-isomer of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol (VI), while from the α-isomer of piperidol (II) we obtained the α-isomer of piperidol (VI). Besides these two stereoisomeric piperidols (VI), we also obtained a third isomer of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol when we reacted 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidone (XII) with either phenylmagnesium bromide or phenyllithium.

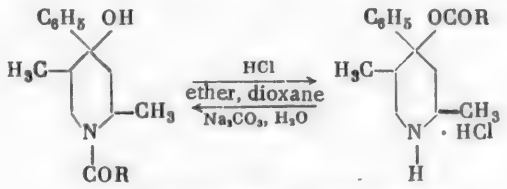
The same isomer of piperidol (VI) was also isolated when the noncrystalline residue, obtained after removal of the α- and γ-isomers of 2,5-dimethyl-4-phenyl-4-piperidol (II) in the reaction of 2,5-dimethyl-4-piperidone

(I) with phenyllithium, was acetylated. The γ-isomer of 1-diethylaminoacetyl-2,5-dimethyl-4-phenyl-4-piperidol (IX) was obtained by the acylation of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol with chloroacetyl chloride, followed by reaction of the 1-chloroacetyl-2,5-dimethyl-4-piperidol (XIV) formed with diethylamine.



(XIV) (IX)

The γ-isomers of 1-acetyl- and 1-propionyl-2,5-dimethyl-4-phenyl-4-piperidol when treated with dry hydrogen chloride in either dioxane or ether solution are, respectively, converted to the hydrochlorides of the acetic (XV) and propionic (XVI) esters of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol. The latter in weakly alkaline media are reconverted to the original piperidols (VI) and (VII) [2].



(XV) R = CH_3, (XVI) R = C_2H_5

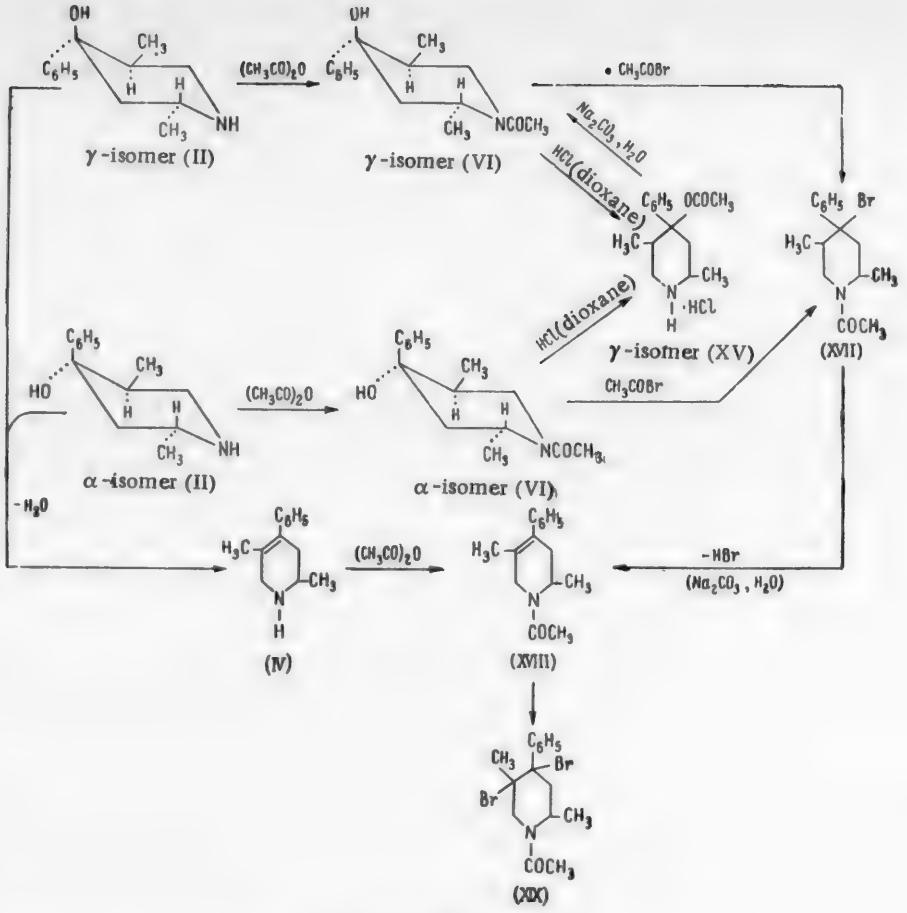
The hydrochlorides of the acetate (XV) and propionate (XVI) of 2,5-dimethyl-4-phenyl-4-piperidol are inactive as analgesics.

The absence of analgesic activity when an N-methyl radical is replaced by hydrogen also occurs in other series of synthetic analgesics [3]. The α-isomer of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol (VI) under the same conditions (treatment with hydrogen chloride in dioxane) is not converted to the hydrochloride of the acetate of the α-isomer of 2,5-dimethyl-4-phenyl-4-piperidol, but instead gives the same hydrochloride of the acetate of the γ-isomer (XV) described above, which when treated with aqueous soda solution is converted to the γ-isomer of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol (VI).

A similar change in the configuration of the α-isomer to that of the corresponding γ-isomer was also observed by us in the replacement of the hydroxyl group in piperidols (VI) by bromine. Both of the stereoisomeric alcohols (VI) when reacted with acetyl bromide [4] give the same γ-isomer of 1-acetyl-2,5-dimethyl-4-phenyl-4-bromopiperidine (XVII).

The bromo derivative (XVII) is easily debrominated to give 1-acetyl-2,5-dimethyl-4-phenyl-1,2,3,6-tetrahydropyridine (XVIII). The latter was also obtained by the acetylation of 2,5-dimethyl-4-phenyl-1,2,3,6-tetrahydropyridine (IV), described above. The bromination of 1-acetyl-2,5-dimethyl-4-phenyl-1,2,3,6-tetrahydropyridine gave 1-acetyl-2,5-dimethyl-4-phenyl-4,5-dibromopiperidine (XIX) in 87% yield.

The obtained results make it possible to postulate that the γ- and α-isomers of piperidole (II), (III) and (VI) belong to the same series of trans-piperidones (starting products in their synthesis) and differ among themselves in the position of the phenyl radical and hydroxyl group on the fourth carbon atom; here the more stable γ-form corresponds to a trans-position of the methyl groups and a trans-position of the phenyl radical with respect to the methyl group found on carbon 5 of the piperidine ring. In like manner the α-form corresponds to a trans-position of the methyl groups and a cis-position of the phenyl radical with respect to the same methyl group.



EXPERIMENTAL

2,5-Dimethyl-4-phenyl-4-piperidol (II). a) Phenyllithium was obtained from 57 g of lithium and 650 g of bromobenzene in 1000 ml of absolute ether. Then 150 g of 2,5-dimethyl-4-piperidone (I) was added dropwise in three hours. The reaction mixture was stirred for another hour at room temperature, and then it was decomposed with water and hydrochloric acid (first with 200 ml of water, then with 200 ml of 18% hydrochloric acid, and finally with 300 ml of concentrated hydrochloric acid). The water layer was treated with potassium hydroxide (excess). The organic bases that separated were extracted with ether, then dried over sodium sulfate, and finally vacuum-distilled. The following fractions were collected: 1st, 74-199° (3 mm), 29 g; 2nd, 110-160° (3 mm), 93.8 g; 3rd, 160-180° (3 mm), 35.3 g; residue 46 g.

We obtained 25 g of starting 2,5-dimethyl-4-piperidone (I) from the first fraction. The second and third fractions were dissolved in gasoline. The solutions on cooling to room temperature deposited crystals. After the first crops of crystals were removed the mother liquors were evaporated to give a second crop of crystals, which were recrystallized from gasoline. We obtained 38 g of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II) with m.p. 121-122°.

Found %: N 6.59, 6.61. $C_{13}H_{19}ON$. Calculated %: N 6.84.

In addition, we also isolated another 4.6 g of the α-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II) with m.p. 163-166°.

Found %: N 7.18, 7.03. $C_{13}H_{19}ON$. Calculated %: N 6.84.

A noncrystallizing oil remained after removal of the crystalline piperidols (II).

b) A mixture of the stereoisomers of 2,5-dimethyl-4-phenyl-4-piperidol (II) was obtained as described above. For the reaction we took 19 g of lithium, 225 g of bromobenzene, 50 g of 2,5-dimethyl-4-piperidone and 500 ml of absolute ether. Fractional distillation of the principal reaction products in vacuo gave 6 g of unreacted 2,5-dimethyl-4-piperidone (I) (b.p. 40-93° at 4 mm), 36.9 g of mixed piperidole (II) (b.p. 138-185° at 3 mm), and 6.3 g of residue. Recrystallization of the mixed piperidols (II) from gasoline gave 15.2 g of crystals with m.p. 104-111°, and 21.7 g of noncrystallizing residue. A chloroform solution of 3 g of the crystals with m.p. 104-111° was passed through a column containing aluminum oxide (the column height was 90 cm and the diameter was 1.5 cm). For elution we first used chloroform, and then methanol. We obtained 2.3 g of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II) with m.p. 121-122° and 0.4 g of the α-isomer with m.p. 164-166°. The γ-isomer is eluted with chloroform and is found in the first portions of the solvent, while the α-isomer is eluted with methanol toward the end of chromatographing.

Separation of mixed stereoisomeric 1,2,5-trimethyl-4-phenyl-4-piperidole (III) using chromatographing on aluminum oxide. The mixture of stereoisomeric 1,2,5-trimethyl-4-phenyl-4-piperidols (III) was obtained by the procedure described in previous communications [1]. For the reaction we took 50 g of lithium, 565 g of bromobenzene, 423 g of 1,2,5-trimethyl-4-piperidone and 800 ml of ether. Fractional distillation of the principal reaction products in vacuo gave 43 g of starting 1,2,5-trimethyl-4-piperidone (b.p. 54-56° at 3.5 mm), 470 g of mixed piperidols (III) (b.p. 136-138° at 2.5 mm), and 70 g of residue.

Recrystallization of the mixed piperidols (III) from gasoline gave 210 g of the γ-isomer of 1,2,5-trimethyl-4-phenyl-4-piperidol with m.p. 107-108°, 173 g of crystals with m.p. 68-76°, and 85 g of a noncrystallizing residue.

a) A chloroform solution of 4 g of the crystals with m.p. 68-76° was passed through a column containing aluminum oxide (height of lower part of column 80 cm, diameter 1.5 cm, height of upper part of column 10 cm, diameter 2.5 cm, aluminum oxide 160 g). For elution we first used chloroform, and then methanol. We obtained 2.2 g of the γ-isomer with m.p. 105-107° (after washing with gasoline and drying in a desiccator), and 1.3 g of the α-isomer of 1,2,5-trimethyl-4-phenyl-4-piperidol (III) with m.p. 103-105° (recrystallization from gasoline). The γ-isomer is eluted with chloroform and is found in the first portions of solvent, while the α-isomer is eluted with methanol toward the end of chromatographing.

b) A chloroform solution of 20 g of the noncrystalline mixture of piperidols (III) was passed through a column filled with aluminum oxide (height of the lower part of the column 100 cm, diameter 1.5 cm, height of the upper part of the column 40 cm, diameter 2.5 cm, aluminum oxide 280 g). The elution was run as described above, first with chloroform, and then with methanol.

The following fractions were obtained in the order: 0.9 g of the γ-isomer with m.p. 105-107.5°, 4.4 g of the β-isomer with m.p. 96-102°, 0.6 g of crystals with m.p. 118-120°, and 8.6 g of the α-isomer of 1,2,5-trimethyl-4-phenyl-4-piperidol with m.p. 105-107°. The α-isomer was eluted toward the end of chromatographing with methanol. The melting points (and also the weights) were determined after each eluted fraction had been recrystallized from gasoline.

Methylation of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol. a) A mixture of 0.5 g of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II) (m.p. 121-122°) and 0.6 g of formalin was heated in a sealed ampoule at 130-140° for four hours. The reaction mass was dissolved in 10 ml of water and then treated with potassium hydroxide. The organic bases that separated here were extracted with ether. After drying over sodium sulfate and removal of the ether by distillation we obtained 0.6 g of residue, which crystallized when gasoline was added. We obtained 0.5 g of the γ-isomer of 1,2,5-trimethyl-4-phenyl-4-piperidol (III) with m.p. 107-108°, which did not depress the melting point when mixed with an authentic specimen of this alcohol.

b) A solution of 1 g of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II) in 30 ml of anhydrous benzene was treated with 3.5 g of methyl iodide. Here an oil deposited on the bottom of the flask. The mixture was heated for five hours at benzene boil. The benzene was decanted, while the residue was dried in a desiccator (1.8 g). Recrystallization of the residue from alcohol gave 0.5 g of the methiodide of the γ-isomer of 1,2,5-trimethyl-4-phenyl-4-piperidol with m.p. 217-221°, which did not depress the melting point when mixed with the methiodide, obtained directly from the γ-isomer of 1,2,5-trimethyl-4-phenyl-4-piperidol (III) and methyl iodide.

Methylation of the α-isomer of 2,5-dimethyl-4-phenyl-4-piperidol. For reaction we took 0.5 g of the α-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II) (m.p. 163-166°) and 0.6 g of formalin. The reaction was run as described above. We obtained 0.4 g (after two recrystallizations from gasoline) of the α-isomer of 1,2,5-trimethyl-4-phenyl-4-piperidol (III) with m.p. 106-107°. The mixed melting point with the authentic specimen was not depressed.

2,5-Dimethyl-4-phenyl-1,2,3,6-tetrahydropyridine (IV). a) A mixture of 1.5 g of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II) with m.p. 121-122°, 4 g of 70% sulfuric acid and 0.3 g of fused copper sulfate was heated on the boiling water bath for 4.5 hours. The mixture was diluted with 20 ml of water and then cautiously treated with soda until completely saturated. The free base was extracted with ether, and after drying over sodium sulfate, was vacuum-distilled. We obtained 1.1 g of 2,5-dimethyl-4-phenyl-1,2,3,6-tetrahydropyridine (IV) with b.p. 93° (2.5 mm).

The picrate had m.p. 138-141° (from alcohol).

Found %: N 13.78, 13.35. $C_{19}H_{20}O_7N_4$. Calculated %: N 13.46.

The hydrochloride of 2,5-dimethyl-4-phenyl-1,2,3,6-tetrahydropyridine had m.p. 143-145° (from acetone).

Found %: N 6.59, 6.56. $C_{13}H_{18}NCl$. Calculated %: N 6.26.

b) A mixture of 0.5 g of the α-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II) (m.p. 163-166°), 1.5 g of 70% sulfuric acid and 0.1 g of fused copper sulfate was heated at 90-95° for five hours. The mixture was diluted with water and then carefully treated with soda until saturated. The free base was extracted with ether and then dried over sodium sulfate. Removal of the ether by distillation left 0.3 g of a mobile liquid, from which a picrate with m.p. 141-143° (from alcohol) and a hydrochloride with m.p. 144-145° (from acetone) were obtained. The respective mixtures of the obtained picrate and hydrochloride with the picrate and hydrochloride of 2,5-dimethyl-4-phenyl-1,2,3,6-tetrahydropyridine, obtained from the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol, failed to show a melting point depression.

1,2,5-Trimethyl-4-phenyl-1,2,3,6-tetrahydropyridine (V). a) A mixture of 2 g of the α-isomer of 1,2,5-trimethyl-4-phenyl-4-piperidol (III) (m.p. 106-107°), 4 g of 70% sulfuric acid and 0.5 g of fused copper sulfate was heated at 90-95° for five hours. The mixture was diluted with 20 ml of water and then carefully treated with soda until completely saturated. The free base was extracted with ether, and after drying over sodium sulfate, was vacuum-distilled. We obtained 1.3 g of 1,2,5-trimethyl-4-phenyl-1,2,3,6-tetrahydropyridine (V) with b.p. 85° (2.5 mm), n_D^{17} 1.5479. The picrate had m.p. 126-128° (from alcohol), and failed to depress the melting point when mixed with the picrate of the dehydration product obtained from the γ-isomer of 1,2,5-trimethyl-4-phenyl-4-piperidol [5].

b) A mixture of 3 g of the γ-isomer of 1,2,5-trimethyl-4-phenyl-4-piperidol (III) (m.p. 107-108°) and 10 ml of concentrated hydrochloric acid was heated at 90-95° for three hours. The acid was removed by vacuum-distillation. The glassy residue was dissolved in water. To obtain the free base the water solution was treated with soda, but the addition of the soda gave a floating oil layer, which proved to be insoluble in both saturated aqueous soda solution and in ether. Only after vigorous stirring for a long time with a large excess of soda did the oil layer disappear and the product become soluble in ether. From the latter we isolated 1.8 g of 1,2,5-trimethyl-4-phenyl-1,2,3,6-tetrahydropyridine (V) with b.p. 92-94° (3 mm). It was converted to the picrate, which, the same as the authentic specimen [5], had m.p. 126-128°.

c) A mixture of 1.5 g of 2,5-dimethyl-4-phenyl-1,2,3,6-tetrahydropyridine (IV) and 1.8 g of formalin was heated in a sealed ampoule for four hours at 130-140°. The mixture was diluted with 20 ml of water and then carefully treated with potassium hydroxide until completely saturated. The free base was extracted with ether, and after drying over sodium sulfate, was vacuum-distilled. We obtained 0.9 g of 1,2,5-trimethyl-4-phenyl-1,2,3,6-tetrahydropyridine (V) with b.p. 85° (2.5 mm). The picrate had m.p. 126-128° (from alcohol), and did not depress the melting point when mixed with the picrate of the dehydration product obtained from the γ-isomer of 1,2,5-trimethyl-4-phenyl-4-piperidol.

1-Acetyl-2,5-dimethyl-4-phenyl-4-piperidol (VI). a) Acetylation of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol. A solution of 1.8 ml of acetic anhydride in 5 ml of benzene was cautiously added with cooling to a mixture of 3 g of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (m.p. 121-122°) and 10 ml of anhydrous benzene. The reaction mixture was heated for one hour at benzene boil. The excess acetic anhydride,

benzene and acetic acid were removed by distillation under a slight vacuum. The residue crystallized when absolute ether was added. The crystals were filtered and dried; weight 3.1 g, m.p. 104-106°. Two recrystallizations from gasoline gave 2.8 g of the γ-isomer of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol (VI) with m.p. 108-110°.

Found %: N 5.86, 5.65. $C_{15}H_{21}O_2N$. Calculated %: N 5.67.

b) Acetylation of the α-isomer of 2,5-dimethyl-4-phenyl-4-piperidol. For reaction we took 1 g of the α-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (m.p. 163-166°), 1.3 ml of acetic anhydride and 10 ml of anhydrous benzene. A precipitate was obtained, when the mixture was heated for 1.5 hours on the water bath, which was filtered and washed well with benzene. We obtained 1.1 g of crystals with m.p. 199-201°. After recrystallization from benzene the α-isomer of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol (VI) melted at 200-202°.

Found %: N 5.64, 5.39. $C_{15}H_{21}O_2N$. Calculated %: N 5.67.

c) Phenylmagnesium bromide, prepared from 6 g of magnesium and 36 g of bromobenzene in 350 ml of ether, was added in two hours to a solution of 35 g of 1-acetyl-2,5-dimethyl-4-piperidone (XII) (m.p. 60-61°) in 200 ml of absolute ether. The next day, after heating for one hour, the reaction mixture was treated under cooling with 150 ml of saturated ammonium chloride solution. The ether layer was separated. In approximately an hour 11.7 g of a crystalline precipitate, with m.p. 173-176°, deposited from the ether layer. Recrystallization of the precipitate from anhydrous alcohol gave the third stereoisomeric form of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol (VI) with m.p. 179-180°.

Found %: N 5.60, 5.98. $C_{15}H_{21}O_2N$. Calculated %: N 5.67.

Treatment of the water layer, saturated with ammonium chloride, with caustic, followed by extraction with ether, and distillation of the extracted products in vacuo gave 10.4 g of a viscous liquid with b.p. 117-119° (2.5 mm), which crystallized in the receiver. Recrystallization from ether gave 9.2 g of the starting 1-acetyl-2,5-dimethyl-4-piperidone (XII) with m.p. 56-58°.

In the experiments where either phenylmagnesium bromide or phenyllithium was reacted, not with the pure stereoisomer of 1-acetyl-2,5-dimethyl-4-piperidone with m.p. 60-61°, but instead with the mixture of stereoisomeric piperidones (XII), the same isomer of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol with m.p. 179-180° was obtained.

d) The synthesis of 2,5-dimethyl-4-phenyl-4-piperidol (II) from 2,5-dimethyl-4-piperidone (I) and phenyllithium was described in the first experiment. A noncrystallizing oil remains after the crystalline γ- and α-isomers of piperidol (II) have been removed from the reaction products. A benzene solution of this residue (11.2 g) was heated for one hour with 16.3 g of acetic anhydride. The benzene and acetic anhydride were removed by distillation under a slight vacuum, and the residue was dissolved in absolute ether. After standing for some time the ether solution deposited 0.4 g of crystals with m.p. 170-174°, which after recrystallization from benzene melted at 188-179°, and failed to depress the melting point when mixed with the above-described specimen of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol (VI).

γ-Isomer of 1-propionyl-2,5-dimethyl-4-phenyl-4-piperidol (VII). A solution of 1 g of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II) in 10 ml of anhydrous benzene was treated with 1.4 ml of propionic anhydride. The mixture was heated for one hour. The benzene and excess propionic anhydride were vacuum-distilled. The residue was recrystallized from ether. We obtained 0.7 g of the γ-isomer of 1-propionyl-2,5-dimethyl-4-phenyl-4-piperidol (VII) with m.p. 81-83°.

Found %: N 5.43, 5.57. $C_{16}H_{23}O_2N$. Calculated %: N 5.36.

When a mixture of 2 g of the hydrochloride of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (m.p. 210-211°), 30 ml of propionic anhydride and 2 ml of propionyl chloride was heated on the boiling water bath for ten hours we obtained 1.6 g of 1-propionyl-2,5-dimethyl-4-phenyl-1,2,3,6-tetrahydropyridine as a viscous liquid with b.p. 173-174° (2.5 mm), n_D^{20} 1.5562.

Found %: N 6.15, 6.09. $C_{16}H_{21}ON$. Calculated %: N 5.76.

1-Benzoyl-2,5-dimethyl-4-phenyl-4-piperidol (VIII). Benzoyl chloride (5.8 g) was added gradually, with cooling and stirring, to 5 g of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II) and a solution of 6 g of

sodium hydroxide in 15 ml of water. The mixture was stirred for four hours at room temperature, and then extracted four times with 50 ml portions of ether. The reaction product after drying was vacuum-distilled. We obtained 2 g of a substance with b.p. 198° (2.5 mm), which crystallized when gasoline was added. Recrystallization from acetone gave 1.5 g of the γ-isomer of 1-benzoyl-2,5-dimethyl-4-phenyl-4-piperidol (VIII) with m.p. 187.5-188°.

Found %: N 4.33, 4.69. $C_{20}H_{23}O_2N$. Calculated %: N 4.53.

b) A solution of 70 g of mixed stereoisomeric 1-benzoyl-2,5-dimethyl-4-piperidones (XIII) in 200 ml of ether was added in four hours, with cooling and vigorous stirring, to the phenylmagnesium bromide obtained from 9 g of magnesium and 52 g of bromobenzene in 700 ml of ether. A copious white precipitate was obtained. After heating at ether boil for two hours, 500 ml of water was added. The ether layer was separated and dried over sodium sulfate. The residue after distilling off the ether was vacuum-distilled. The following fractions were obtained: first, 74-130° (3 mm), 6 g; second, 130-230° (3 mm), 45.7 g; third, 230-232° (2.5 mm), 19 g; residue 7 g.

From the first and second fractions, which crystallized in the receivers, we isolated 8.7 g of one of the stereoisomeric 1-benzoyl-2,5-dimethyl-4-piperidones (XIII) with m.p. 65.5-67.5°. From the third fraction by recrystallization from benzene we isolated 14 g of 1-benzoyl-2,5-dimethyl-4-phenyl-4-piperidol (VIII) with m.p. 89-94°.

Found %: N 3.94, 4.16. $C_{20}H_{23}O_2N$. Calculated %: N 4.53.

γ-Isomer of 1-diethylaminoacetyl-2,5-dimethyl-4-phenyl-4-piperidol (IX). A solution of 2 g of chloroacetyl chloride in 50 ml of benzene was added with stirring to a cooled to 0° solution of 7.5 g of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II) in 100 ml of anhydrous benzene. The mixture was stirred for 1.5 hours at room temperature. The obtained precipitate was filtered, and washed well on the filter with benzene. We obtained 4 g of the hydrochloride of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol with m.p. 210-211° (from a mixture of acetone and alcohol).

Found %: N 5.20, 5.88. $C_{15}H_{20}O_2NCl$. Calculated %: N 5.79.

Removal of the solvent from the mother liquor by distillation gave 4.8 g of 1-chloroacetyl-2,5-dimethyl-4-phenyl-4-piperidol (XIV) as a yellow glass, which was dissolved in 15 ml of benzene and then added gradually to 5.7 g of diethylamine at the boiling point of the latter. Then the mixture was heated for another six hours. The benzene was distilled off. The residue was dissolved in 7 ml of water, treated with sodium hydroxide, and extracted with ether. Vacuum-distillation of the extracted products gave 2.1 g of a viscous liquid with b.p. 199-203° (2.5 mm), which crystallized when gasoline was added. We obtained colorless fine-grained crystals of the γ-isomer of 1-diethylaminoacetyl-2,5-dimethyl-4-phenyl-4-piperidol (IX) with m.p. 136-139°.

Found %: N 9.07, 8.78. $C_{19}H_{30}O_2N_2$. Calculated %: N 8.80.

γ-Isomer of 1-methylsulfonyl-2,5-dimethyl-4-phenyl-4-piperidol (X). A solution of 0.5 g of methanesulfonyl chloride in 10 ml of benzene was added in drops to a cooled solution of 1.75 g of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II) in 15 ml of anhydrous benzene. The obtained precipitate (1.2 g) of the hydrochloride of piperidol (II) was filtered and washed with benzene. Removal of the benzene by distillation left 0.55 g of 1-methylsulfonyl-2,5-dimethyl-4-phenyl-4-piperidol (X), which after recrystallization from acetone had m.p. 168-170°.

Found %: N 4.76, 4.95. $C_{14}H_{21}O_3NS$. Calculated %: N 4.94.

γ-Isomer of 1-benzenesulfonyl-2,5-dimethyl-4-phenyl-4-piperidol (XI). For reaction we took 0.5 g of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (II), 1 g of 12% sodium hydroxide solution and 2.5 g of benzenesulfonyl chloride. The mixture was heated with stirring for nine hours on the water bath. The obtained precipitate was filtered and then recrystallized from anhydrous alcohol. We obtained 0.2 g of 1-benzenesulfonyl-2,5-dimethyl-4-phenyl-4-piperidol (XI) with m.p. 127-129°.

Found %: N 4.03, 4.02. $C_{19}H_{23}O_3NS$. Calculated %: N 4.06.

Action of hydrogen chloride on the γ- and α-isomers of 1-acetyl(propionyl)-2,5-dimethyl-4-phenyl-4-piperidol. a) A white precipitate was obtained when dry hydrogen chloride was passed into a solution of 0.2 g

of the γ-isomer of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol (VI) (m.p. 108-110°) in absolute ether, which after recrystallization from acetone gave 0.15 g of the hydrochloride of the acetate of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (XV) with m.p. 137-138°.

Found %: Cl 12.13; N 4.70, 4.80. $C_{15}H_{22}O_2NCl$. Calculated %: Cl 12.52; N 4.93.

A water solution of 0.5 g of the hydrochloride of the acetate of 2,5-dimethyl-4-phenyl-4-piperidol (XV) was treated with soda and ether. From the ether solution after drying we obtained 0.3 g of crystals with m.p. 109-110°, which failed to depress the melting point when mixed with the γ-isomer of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol (VI).

b) A stream of dry hydrogen chloride was passed through a solution of 4 g of the γ-isomer of 1-propionyl-2,5-dimethyl-4-phenyl-4-piperidol (VII) (m.p. 81-83°) in absolute ether. The obtained precipitate of the hydrochloride of the propionate of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (XVI), after recrystallization from acetone, weighed 2.5 g and had m.p. 125-126°.

Found %: Cl 11.71; N 4.30, 4.54. $C_{16}H_{24}O_2NCl$. Calculated %: Cl 11.93; N 4.76.

When the propionate hydrochloride (XVI) in aqueous solution was treated with soda it reverted to the γ-isomer of 1-propionyl-2,5-dimethyl-4-phenyl-4-piperidol (VII) with m.p. 81-83°.

c) Dry hydrogen chloride (4.3 g) was passed into a hot solution of 0.8 g of the α-isomer of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol (VI) (m.p. 200-202°) in 80 ml of anhydrous dioxane. A white precipitate deposited in two days, which after recrystallization from acetone gave 0.6 g of the hydrochloride with m.p. 136-138°, and not depressing the melting point when mixed with the hydrochloride of the acetate of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol (XV). A water solution of 0.3 g of the 2,5-dimethyl-4-phenyl-4-piperidol acetate hydrochloride (XV) was treated with soda and ether. From the ether solution after drying we obtained 0.1 g of crystals with m.p. 108-109°, which did not depress the melting point when mixed with the γ-isomer of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol (VI).

1-Acetyl-2,5-dimethyl-4-phenyl-4-bromo(chloro)-piperidine. a) The γ-isomer of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol (VI) (m.p. 108-110°) (0.5 g) was dissolved in 3.5 ml of freshly distilled acetyl bromide. Within five minutes a precipitate of the hydrobromide of the acetate of the γ-isomer of 2,5-dimethyl-4-phenyl-4-piperidol with m.p. 130-130.5° was obtained (0.3 g). When treated with an aqueous solution of soda it reverted to the original γ-isomer of piperidol (VI). Partial removal of acetyl bromide from the mother liquor, remaining after separation of the acetate hydrobromide, led to obtaining 0.1 g (after recrystallization from acetone) of 1-acetyl-2,5-dimethyl-4-phenyl-4-bromopiperidine (XVII) with m.p. 159-161°.

Found %: C 57.82, 58.13; H 6.40, 6.44; N 4.36, 4.42; Br 26.13, 25.59. $C_{15}H_{20}ONBr$. Calculated %: C 58.01; H 6.45; N 4.51; Br 25.80.

b) The α-isomer of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol (VI) (m.p. 200-202°) (0.5 g) was dissolved in 3.5 ml of acetyl bromide. After one hour the excess acetyl bromide was vacuum-distilled. From the residue after two recrystallizations from acetone we obtained 0.3 g of 1-acetyl-2,5-dimethyl-4-phenyl-4-bromopiperidine (XVIII) with m.p. 153-154°, and failing to depress the melting point when mixed with the same product, obtained from the γ-isomer of piperidol (VI).

c) A mixture of 1 g of the γ-isomer of 1-acetyl-2,5-dimethyl-4-phenyl-4-piperidol (VI) (m.p. 108-110°) and 0.6 ml of acetyl chloride was heated in benzene solution in the presence of 0.2 g of magnesium metal for 16 hours. After removal of the solvent and acetyl chloride by distillation, the residue was washed with ether, and then recrystallized from benzene. We obtained 0.2 g of 1-acetyl-2,5-dimethyl-4-phenyl-4-chloropiperidine as colorless crystals with m.p. 143-146°. It failed to change when kept in the air.

Found %: N 5.30, 5.43. $C_{15}H_{20}ONCl$. Calculated %: N 5.27.

1-Acetyl-2,5-dimethyl-4-phenyl-1,2,3,6-tetrahydropyridine (XVIII). a) A water solution of 0.5 g of 1-acetyl-2,5-dimethyl-4-phenyl-4-bromopiperidine (XVII) was treated first with 8% soda solution and then with ether. From the ether extract, after drying over sodium sulfate and removal of the ether by distillation, we obtained 0.3 g of 1-acetyl-2,5-dimethyl-4-phenyl-1,2,3,6-tetrahydropyridine (XVIII) as colorless crystals with m.p. 65-67° (from gasoline).

Found %: N 6.41, 6.08. $C_{15}H_{19}ON$. Calculated %: N 6.11.

b) A mixture of 1 g of 2,5-dimethyl-4-phenyl-1,2,3,6-tetrahydropyridine (IV) and 1.6 ml of acetic anhydride in 5 ml of anhydrous benzene was heated on the boiling water bath for 1.5 hours. The acetic anhydride was vacuum-distilled, and the residue was dissolved in water, neutralized with soda solution, and extracted with ether. From the ether solution we obtained 0.6 g of 1-acetyl-2,5-dimethyl-4-phenyl-1,2,3,6-tetrahydropyridine (XVIII) with m.p. 67-78° (from gasoline), which did not depress the melting point when mixed with the above-described specimen of this product.

1-Acetyl-2,5-dimethyl-4-phenyl-4,5-dibromopiperidine (XIX). A solution of 0.11 ml of bromine in 5 ml of carbon tetrachloride was added slowly and with cooling to a solution of 0.5 g of 1-acetyl-2,5-dimethyl-1,2,3,6-tetrahydropyridine (IV) in 10 ml of carbon tetrachloride. The obtained orange precipitate was separated, washed thoroughly with gasoline, and dried. We obtained 0.5 g of 1-acetyl-2,5-dimethyl-4-phenyl-4,5-dibromopiperidine (XIX), which deliquesces in the air. The compound changed to an oil when heated to 38°.

Found %: N 3.28, 3.32. $C_{15}H_{19}ONBr$. Calculated %: N 3.59.

SUMMARY

2,5-Dimethyl-4-phenyl-4-piperidol was synthesized. From the corresponding isomers of this alcohol we obtained the stereoisomeric 1,2,5-trimethyl-4-phenyl-4-piperidols and 1-acyl-2,5-dimethyl-4-phenyl-4-piperidols. In a number of cases (during dehydration, action of hydrogen chloride, treatment with acetyl bromide) we observed a conversion of the α-isomer of the piperidol to the γ-isomer.

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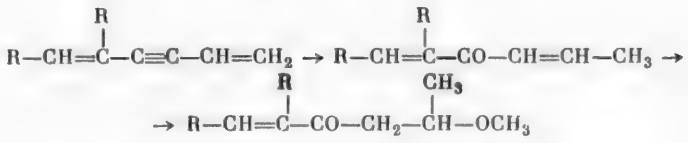
ACETYLENE DERIVATIVES

CXCIV. HYDRATION OF DIVINYLACETYLENE AND VINYLISOPROPENYLACETYLENE IN ALCOHOL SOLUTIONS

I.N. Nazarov,* S.A. Vartanian and S.G. Matsoian

Based on numerous examples it was shown in our laboratory that divinylacetylenic hydrocarbons, when heated in aqueous methanol solution in the presence of sulfuric acid and mercuric sulfate, are easily hydrated with the formation of the corresponding dienones. In all cases the water adds in such manner that the oxygen is found on the carbon atom attached to the substituted vinyl radical.

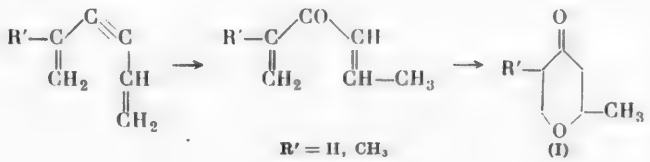
It was established that the hydration rate depends on the structure of the dienyne. Divinylacetylene itself and the symmetrically substituted dienynes are hydrated with the greatest difficulty. The introduction of one, and especially of two, substituents in one of the vinyl radicals of the dienyne (not symmetrical substitution) greatly accelerates the hydration reaction. The hydration rate again decreases as the size of the substituent is increased. The dienones formed under the reaction conditions add the elements of methyl alcohol and are converted to β-methoxy ketones.



The addition of methyl alcohol proceeds in such manner that the methoxyl group is always found in the β-position to the carbonyl group [1].

It seemed of interest to determine if it was possible to hydrate dienynes in the presence of other alcohols, which would permit obtaining various β-alkoxy ketones. It proved that, depending on the conditions used, this reaction leads to the formation of either the corresponding β-alkoxy ketones or to tetrahydro-γ-pyrones. The ease and the time needed to hydrate dienynes also depend on the nature of the alcohol; the hydration rate decreases with branching and increase in the molecular weight of the alcohol.

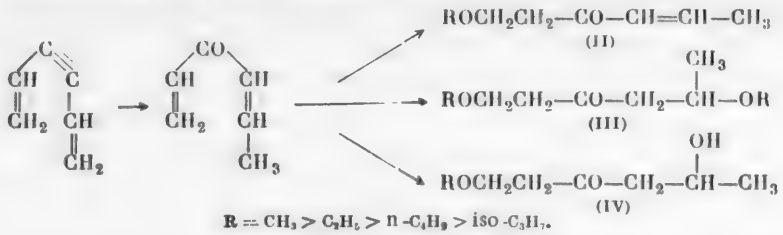
The corresponding tetrahydro-γ-pyrones are obtained in 50% yield when divinylacetylene and vinylisopropenylacetylene are heated in a 50-60% aqueous solution of either ethyl or methyl alcohol, in the presence of mercuric sulfate and sulfuric acid [1, 2].



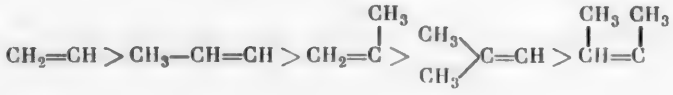
R′ = H, CH_3 (I)

*Deceased.

The hydration of divinylacetylene in 80-95% alcohol solutions gives, together with pyrone (I), also substantial amounts of a mixture of the three alkoxy ketones (II-IV).

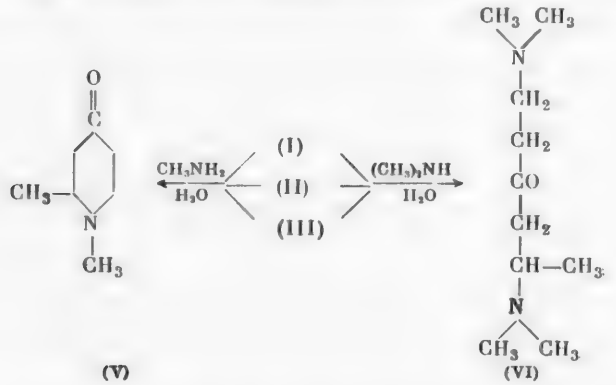


The addition of alcohols proceeds more rapidly at the vinyl radical of vinyl propenyl ketone, and in accordance with this the monomethoxy ketones (II) are formed in the larger amounts. The rate with which alcohols (and also amines and other compounds) add to the vinyl radicals of α,β-unsaturated ketones decreases in the following order:



A disubstituted vinyl group proves to be incapable of adding alcohols (even methanol) [3]. The propenyl group adds alcohols more readily than does the isopropenyl group, while the unsubstituted vinyl group shows the easiest additions of all.

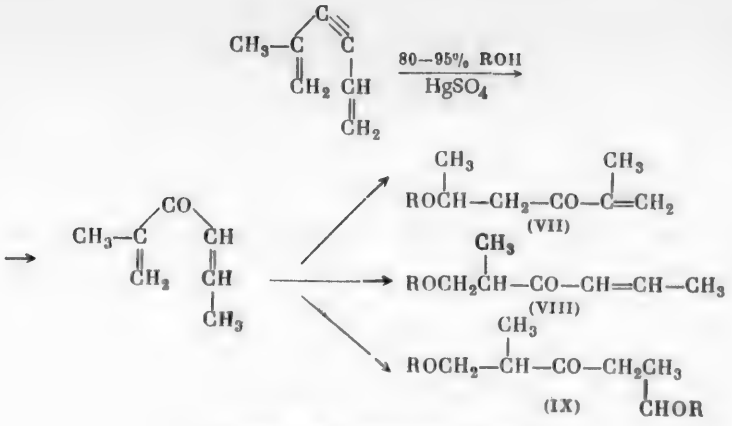
The reaction of either aqueous methylamine or dimethylamine solution with ketones (I-IV) yields, as the result of ammonolysis, either 1,2-dimethyl-4-piperidone (V) [4] or 1,5-bis(dimethylamino)-3-hexanone (VI).



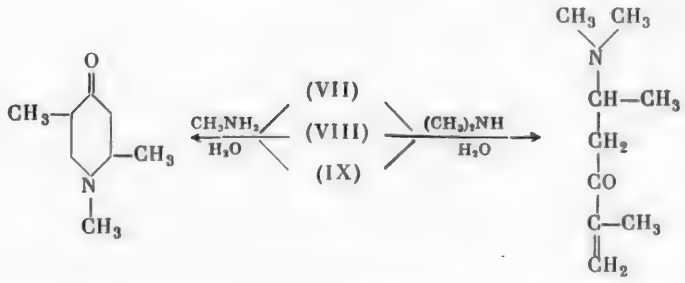
On hydrolysis with 10% sulfuric acid the alkoxy ketones (II-IV) are converted to 2-methyltetrahydro-γ-pyrone (I).

The main reaction products when vinylisopropenylacetylene [6] is hydrated in 80-95% alcohol solutions are the corresponding β-alkoxy ketones (VII-IX).

In the case of primary alcohols (methyl, ethyl, n-butyl) a mixture of all three alkoxy ketones (VII, VIII, IX) is formed, in which connection the low-boiling monoalkoxy ketones (VII), formed as the result of the alcohol adding to the propenyl group, are obtained in much larger amounts than the isomeric high-boiling monoalkoxy ketones (VIII), formed as the result of the alcohol adding to the isopropenyl group. If the hydration of vinylisopropenylacetylene is run in isopropyl alcohol solution, then the solitary reaction product is the monoalkoxy ketone (VII, R = iso-C_3H_7), and, consequently, isopropyl alcohol already proves to be completely incapable of adding to the isopropenyl group of propenyl isopropenyl ketone. The reaction of either aqueous methylamine or dimethylamine with ketones (VII, VIII, IX) gave, respectively, as the result of ammonolysis, either 1,2,5-trimethyl-4-piperidone [4] or 2-dimethylamino-5-methyl-5-hexan-4-one [5] in good yields.



$R = CH_3 > C_2H_5 > iso\text{-}C_3H_7 > n\text{-}C_4H_9$.



EXPERIMENTAL

Hydration of divinylacetylene to 2-methyltetrahydro-4-pyrone. Divinylacetylene (100 g) was added dropwise in 18 hours with stirring to a boiling mixture of 200 g of 50% aqueous methanol, 3 ml of sulfuric acid and 3 g of mercuric sulfate. The experiment was run for a total of 40 hours, and during this time another 21 g of mercuric sulfate (a total of 24 g) was added in small portions. Most of the methanol was distilled off, while the product was salted out with potash, extracted with ether, dried over sodium sulfate, and then fractionally distilled. We obtained 62 g of 2-methyltetrahydro-4-pyrone (I) with b.p. 65-68° (15 mm), n_D^{20} 1.4440. The semicarbazone had m.p. 169° and did not depress the melting point when mixed with an authentic specimen.

We recovered 23 g of divinylacetylene from the distilled alcohol. When the experiment was repeated in 50% ethyl alcohol we obtained a lower yield of 2-methyltetrahydro-4-pyrone.

Hydration of divinylacetylene in ethyl alcohol. A mixture of 860 g of 80% ethanol, 5 ml of concentrated sulfuric acid, 3 g of mercuric sulfate and 200 g of divinylacetylene (b.p. 80-83°, n_D^{20} 1.5000) was vigorously stirred at 78-82° for 35 hours. Here small portions of catalyst were added every two hours, and in this way another 48 g of mercuric sulfate was added. Most of the alcohol was distilled off under a slight vacuum, and when it was fractionally distilled at atmospheric pressure we recovered 27 g of divinylacetylene. The reaction mass was neutralized with soda, extracted with ether, dried over sodium sulfate, and fractionally distilled in vacuo. We obtained 136 g of hydration products with b.p. 69-103° (13 mm), n_D^{20} 1.4480, and about 36 g of a tarry residue. Fractional distillation of 200 g of the described hydration products of divinylacetylene, obtained from several experiments, gave the following fractions: 1st, 68-70° (13 mm), n_D^{20} 1.4440, 48 g; 2nd, 98-100° (13 mm), n_D^{20} 1.4419, 31 g; 3rd, 106-108° (11 mm), n_D^{20} 1.4305, 57.2 g; 4th, 115-117° (12 mm), n_D^{20} 1.4435, 5.3 g. We obtained 30.5 g of an intermediate fraction.

The first fraction was 2-methyltetrahydro-4-pyrone (I), the semicarbazone of which had m.p. 169-170°, and did not give a melting point depression with an authentic specimen.

The second fraction was 1-ethoxy-4-hexen-3-one (II), obtained as a mobile yellow liquid.

d_4^{20} 0.9240, MR 40.70; calc. 40.33.

Found %: C 67.91, 67.87; H 10.09, 10.05. $C_8H_{14}O_2$. Calculated %: C 67.60; H 9.86.

The third fraction was 1,5-diethoxy-3-hexanone (III), obtained as a clear liquid.

d_4^{20} 0.9508, MR 51.62; calc. 51.67.

Found %: C 63.87; H 10.67. $C_{10}H_{20}O_2$. Calculated %: C 63.83; H 10.64.

The fourth fraction was apparently 1-ethoxyhexan-5-ol-3-one (IV), formed by the addition of a molecule of ethanol and water to vinyl allyl ketone.

d_4^{20} 0.9996, MR 42.51; calc. 42.32.

Found %: C 59.69, 59.53; H 10.34, 10.34. $C_8H_{16}O_3$. Calculated %: C 60.00; H 10.00.

Oxidation of 1-ethoxy-4-hexen-3-one (II). Thirty grams of powdered potassium permanganate was gradually added in four hours, with stirring and cold-water cooling, to a mixture of 200 g of water and 8 g of ethoxy ketone (II) (b.p. 98-100° at 13 mm, n_D^{20} 1.4413), and then the stirring was continued for another four hours at room temperature. The manganese dioxide was filtered and washed with hot water. The presence of neutral products in the ether extract could not be shown. The water solution was evaporated to dryness on the water bath, and the residue of salts was treated with concentrated hydrochloric acid, extracted with ether, dried over sodium sulfate, and fractionally distilled in vacuo. We obtained 1.7 g of a mixture of formic and acetic acids with b.p. 98-106° (680 mm) (calomel test), and 2.1 g of β-ethoxypropionic acid with b.p. 141-143° (28 mm), n_D^{20} 1.4230.

Found %: Ag 47.93. $C_5H_9O_2Ag$. Calculated %: Ag 48.00.

Hydrolysis of ethoxy ketones (II, III, IV) with the formation of 2-methyltetrahydro-4-pyrone (I). Ten grams of the above-described mixture of ketones (II, III, IV), obtained by the hydration of divinylacetylene in ethyl alcohol (b.p. 65-110° at 12 mm, n_D^{20} 1.4470), 25 g of 10% sulfuric acid and 1 g of mercuric sulfate were stirred with heating on the water bath for four hours. The solution was saturated with potash, extracted with ether, the extract dried over sodium sulfate, and the product fractionally distilled in vacuo. We isolated 4.3 g of 2-methyltetrahydro-4-pyrone with b.p. 60-62° (15 mm), n_D^{20} 1.4440.

The semicarbazone had m.p. 169-170° and did not depress the melting point with an authentic specimen.

Reaction of methylamine with ethoxy ketones (II-IV). A mixture of 15 g of ethoxy ketones (b.p. 65-100° at 12 mm, n_D^{20} 1.4470), 23 g of 24% aqueous methylamine solution and 10 ml of alcohol was heated in a glass ampoule at 65-70° for three hours. The solution was acidified with dilute hydrochloric acid, and the neutral products were extracted with ether, but after distilling off the ether they proved to be present in very small amount. The organic bases were salted out with potash, extracted with ether, dried over sodium sulfate, and fractionally distilled in vacuo. We obtained 6.8 g of the earlier-described [4] 1,2-dimethyl-4-piperidone (V) with b.p. 80-82° (10 mm), n_D^{20} 1.4583. The picrate had m.p. 163-164°, and did not depress the melting point with an authentic specimen.

Reaction of dimethylamine with ethoxy ketones (II-IV). A mixture of 10 g of ethoxy ketones (b.p. 65-110° at 12 mm, n_D^{20} 1.4470) and 23 g of a 25% aqueous dimethylamine solution was heated at 70° for three hours. Then the excess dimethylamine was vacuum-distilled on the water bath at 45°. The residue was acidified with dilute hydrochloric acid, extracted with ether, and after distilling off the ether we obtained a total of about 1 g of neutral products. The water solution was saturated with potash, the bases extracted with ether, the extract dried over sodium sulfate, and the product fractionally distilled in vacuo. We obtained 3.4 g of 1,5-bis(dimethylamino)-3-hexanone (VI) with b.p. 85-87° (9 mm), n_D^{20} 1.4560. The picrate had m.p. 145-146°, and did not depress the melting point with an authentic specimen.

Hydration of divinylacetylene in butanol. A mixture of 250 g of divinylacetylene and 90 g of water was added dropwise in 20 hours with constant stirring to a heated to 95° mixture of 500 g of butyl alcohol, 5 ml of sulfuric acid and 5 g of mercuric sulfate. Stirring at 95-100° was continued for another 48 hours, and during this time 42 g of mercuric sulfate was added in portions. The reaction mixture was neutralized with potash, filtered, and the butyl alcohol vacuum-distilled on the water bath. The residue was extracted with ether, dried over sodium sulfate, and vacuum-distilled. We obtained 105 g of hydration products with b.p. 73-113° (12 mm), n_D^{20} 1.4543. We took 153 g of this mixture, obtained from two experiments, and fractionally distilled in vacuo.

The following fractions were obtained: 1st, 73-75° (30 mm), n_D^{20} 1.4440, 37 g; 2nd, 100-102° (11 mm), n_D^{20} 1.4610, 31 g; 3rd, 135-137° (11 mm), n_D^{20} 1.4313, 12.5 g. We also collected 48.5 g of intermediate fractions.

The first fraction was 2-methyltetrahydro-4-pyrone (I), the semicarbazone of which had m.p. 169°, and did not depress the melting point with an authentic specimen.

The second fraction was 1-butoxy-4-hexen-3-one (II, R = C_4H_9), obtained as a yellowish liquid, d_4^{20} 0.9236, MR 50.52; calc. 49.55.

Found %: C 70.28; H 10.33. $C_{10}H_{18}O_2$. Calculated %: C 70.59; H 10.59.

The compound on standing polymerizes first to a viscous, and then to a hard brittle mass.

The third fraction was 1,5-dibutoxy-3-hexanone (III, R = C_4H_9), obtained as a colorless liquid. d_4^{20} 0.9089, MR 70.03; calc. 69.65.

Found %: C 68.60; H 10.86. $C_{14}H_{28}O_3$. Calculated %: C 68.85; H 11.48.

Reaction of methylamine with butoxy ketones (II-IV). A mixture of 10 g of butoxy ketones (II, III, IV, R = C_4H_9) (b.p. 90-135° at 11 mm, n_D^{20} 1.4550), 25 g of a 24% aqueous methylamine solution and 20 ml of alcohol was heated in a glass ampoule on the water bath at 70° for three hours. The excess methylamine was distilled on the water bath at 50° (70 mm), the solution was acidified with dilute hydrochloric acid, and the neutral products were extracted with ether to subsequently give 2.7 g of butyl alcohol with b.p. 115°. The organic bases were salted out with potash, extracted with ether, dried over sodium sulfate, and vacuum-distilled. We obtained 2.3 g of 1,2-dimethyl-4-piperidone with b.p. 78-80° (9 mm), n_D^{20} 1.4580. The picrate had m.p. 163-164°, and did not depress the melting point with an authentic specimen.

Hydration of vinylisopropenylacetylene to 2,5-dimethyltetrahydro-4-pyrone. Vinylisopropenylacetylene [2] (b.p. 40-43° at 40 mm, n_D^{20} 1.4950) (100 g) was added dropwise in 16 hours, with stirring, to a boiling mixture of 200 g of 50% methanol, 3 ml of sulfuric acid and 3 g of mercuric sulfate. Then the heating and stirring was continued for another 18 hours, and during this time another 13 g of mercuric sulfate was added in small portions. The whole experiment lasted 34 hours. The total amount of mercuric sulfate added was 16 g. Most of the methanol was distilled off, while the product was salted out with potash, extracted with ether, dried over sodium sulfate, and fractionally distilled. We obtained 72 g of a hydration product with b.p. 80-83° (40 mm) and n_D^{20} 1.4466. Redistillation at atmospheric pressure gave the following fractions: 1st, 164-166° (680 mm), n_D^{20} 1.4459, 13 g; 2nd, 171-173° (680 mm), n_D^{20} 1.4486, 25 g; 3rd, 180-185° (680 mm), n_D^{20} 1.4476, 15 g.

The first fraction was 1,3-dimethyl-1-cyclopenten-5-one (the semicarbazone had m.p. 172-173°) with some 2,5-dimethyltetrahydro-4-pyrone as impurity.

The second fraction was 2,5-dimethyltetrahydro-4-pyrone.

B.p. 171-173° (680 mm), n_D^{20} 1.4486, d_4^{20} 1.0190, MR 33.70; calc. 33.98.

Found %: C 65.83; H 10.15. $C_7H_{12}O_2$. Calculated %: C 65.52; H 9.38.

The semicarbazone of 2,5-dimethyltetrahydro-4-pyrone had m.p. 169.5-170.5°.

The third fraction was 1,3-dimethyl-3-cyclopenten-5-one (the semicarbazone had m.p. 190-191°) with some 2,5-dimethyltetrahydro-4-pyrone as impurity.

Hydration of vinylisopropenylacetylene in ethyl alcohol. A mixture of 1000 ml of ethyl alcohol, 250 ml of water, 15 ml of sulfuric acid, 5 g of mercuric sulfate and 250 g of vinylisopropenylacetylene (b.p. 45° at 50 mm, n_D^{20} 1.4962) was vigorously stirred at 78-83° for 32 hours. During this time another 32 g of mercuric sulfate (a total of 37 g) was added in small portions. Then the mixture was neutralized with soda, filtered, the alcohol distilled off, and the product extracted with ether, dried over sodium sulfate, and fractionally distilled in vacuo. We obtained 179 g of a mixture of 2,5-dimethyltetrahydro-4-pyrone and ethoxy ketones (VII, VIII, IX) with b.p. 80-114° (12 mm). The tarry residue from the distillation weighed 32 g.

From the distilled alcohol we recovered 35 g of vinylisopropenylacetylene with b.p. 40-42° (41 mm) and n_D^{20} 1.4956.

After repeated fractional distillation of the hydration products in vacuo we isolated the following fractions:

1st, 80-82° (40 mm), n_D^{20} 1.4487, 50 g; 2nd, 76-77° (11 mm), n_D^{20} 1.4460, 80 g; 3rd, 98-100° (11 mm), n_D^{20} 1.4500, 13 g; 4th, 110-112° (12 mm), n_D^{20} 1.4320, 10.5 g.

The first fraction was 2,5-dimethyltetrahydro-4-pyrone with some of the 1,3-dimethylcyclopentenone as impurity. The semicarbazone had m.p. 169.5-170.5°, and did not depress the melting point with the above-described process.

The second fraction was 2-ethoxy-5-methyl-5-hexen-4-one (VII), obtained as a mobile liquid.

d_4^{20} 0.9370, MR 45.80; calc. 44.95.

Found %: C 69.60; H 10.50. $C_9H_{16}O_2$. Calculated %: C 69.23; H 10.02.

We were unable to obtain a crystalline derivative with 2,4-dinitrophenylhydrazine.

The third fraction was 1-ethoxy-2-methyl-5-hexen-3-one (VIII), obtained as a light-yellow mobile liquid.

d_4^{20} 0.9205, MR 45.80; calc. 44.95.

Found %: C 69.78; H 10.30. $C_9H_{16}O_2$. Calculated %: C 69.23; H 10.02.

The fourth fraction was 1,5-diethoxy-2-methyl-3-hexanone (IX), obtained as a colorless mobile liquid.

d_4^{20} 0.9450, MR 55.82; calc. 56.28.

Found %: C 64.61; H 10.71. $C_{11}H_{22}O_3$. Calculated %: C 65.34; H 10.89.

Oxidation of 2-ethoxy-5-methyl-4-hexen-4-one (VII). Powdered potassium permanganate (27 g) was added gradually in four hours, with stirring and ice-water cooling, to 9 g of the ethoxy ketone (b.p. 85-87° at 15 mm, n_D^{20} 1.4454) in 100 ml of water. The manganese dioxide was filtered and washed with hot water. The water solution was extracted with ether, and then evaporated on the water bath to dryness. The residue of salts was acidified with 13 ml of concentrated hydrochloric acid and then thoroughly extracted with ether. The ether was removed by distillation and the mixed acids were fractionally distilled in vacuo. The following fractions were collected: 1st, 45-48° (22 mm), n_D^{20} 1.3869, 1.1 g; 2nd, 48-108° (20 mm), n_D^{20} 1.4109, 0.4 g; 3rd, 108-109° (19 mm), n_D^{20} 1.4270, 1.5 g.

The first fraction was a mixture of formic and acetic acids, which reduced a solution of mercuric chloride. The silver salts of acetic acid were obtained by fractional precipitation.

Found %: Ag 64.73, 64.55. $C_2H_3O_2Ag$. Calculated %: Ag 64.66.

The third fraction was β-ethoxybutyric acid (b.p. 108-109° at 19 mm, n_D^{20} 1.4270).

Removal of the ether by distillation failed to yield any neutral products.

Oxidation of 1-ethoxy-2-methyl-4-hexen-3-one. Powdered potassium permanganate (35 g) was added gradually in five hours, with stirring, at +10°, to a mixture of 14.2 g of the ketone (b.p. 95-98° at 15 mm, n_D^{20} 1.4486) and 150 ml of water. The manganese dioxide was filtered and washed with hot water. The water solution was extracted with ether to remove neutral products, and then it was evaporated on the water bath to dryness. The residue of salts was acidified with 23 ml of concentrated hydrochloric acid, then thoroughly extracted with ether, and after distilling off the ether the acids were fractionally distilled in vacuo. We obtained 1.7 g of formic acid with b.p. 49.51° (28 mm), 98-101° (680 mm), n_D^{20} 1.3863 (reduces a solution of mercuric chloride), and 2.3 g of β-ethoxymethacrylic acid with b.p. 119-120° (24 mm), n_D^{20} 1.4269.

Reaction of methylamine with ethoxy ketones (VII-IX). A mixture of 12 g of the above-described ethoxy ketones (b.p. 80-100° at 11 mm, n_D^{20} 1.4482) and 28 g of a 25% aqueous methylamine solution was heated in a metal ampoule at 70° for 3.5 hours. The excess methylamine was distilled on the water bath at 45° and a vacuum of 70 mm, the solution acidified with hydrochloric acid until weakly acid, and the neutral products, which proved to be present only in trace amount, were extracted with ether. The organic bases were salted out with potash, extracted with ether, dried over sodium sulfate, and fractionally distilled in vacuo.

We obtained 7.2 g of 1,2,3-trimethyl-4-piperidone with b.p. 76-77° (8 mm) and n_D^{20} 1.4565. The picrate had m.p. 161-162°, and did not depress the melting point with an authentic specimen [4].

Reaction of dimethylamine with ethoxy ketones (VII-IX). A mixture of 15 g of mixed ethoxy ketones (b.p. 80-110° at 11 mm, n_D^{20} 1.4482) and 40 g of a 24% aqueous dimethylamine solution was heated in a glass ampoule on the boiling-water bath for four hours. The excess dimethylamine was removed in vacuo on the water bath at 50°. The solution was acidified with hydrochloric acid until weakly acid, and the neutral products were extracted with ether. The organic bases were salted out with potash, extracted with ether, dried over Na_2SO_4, and fractionally distilled in vacuo. We obtained 9.3 g of the earlier-described 2-methyl-5-dimethylamino-2-hexen-3-one [4] with b.p. 80-82° (6 mm), n_D^{20} 1.4560. The picrate had m.p. 125°, and did not depress the melting point with an authentic specimen [5].

Hydration of vinylisopropenylacetylene in isopropyl alcohol. A mixture of 600 g of isopropyl alcohol, 80 ml of water, 5 ml of sulfuric acid, 200 g of vinylisopropenylacetylene (b.p. 45° at 50 mm, n_D^{20} 1.4960) and 12 g of mercuric sulfate was heated at 70° for 20 hours. Then 150 ml of acetone was added to obtain a homogeneous solution, and the stirring at mixture-boil continued for 26 hours. During this time another 19 g of mercuric sulfate (a total of 31 g) was added in small portions. The reaction product was neutralized with potash and filtered. Most of the isopropyl alcohol was vacuum-distilled on the water bath at 60°, while the product was extracted with ether, dried over sodium sulfate, and fractionally distilled. We obtained 63 g of recovered dienyne (b.p. 45-46° at 45 mm, n_D^{20} 1.4960) and 57 g of 2-isopropoxy-5-methyl-5-hexen-4-one (VII, R = iso-C_3H_7) as a pale-yellow liquid.

B.p. 79-81° (14 mm), n_D^{20} 1.4620, d_4^{20} 0.9340, MR 50.20; calc. 49.58.

Found %: C 70.36, 70.33; H 10.38, 10.77. $C_{10}H_{18}O_2$. Calculated %: C 70.59; H 10.59.

Hydration of vinylisopropenylacetylene in butanol. A mixture of 190 g of vinylisopropenylacetylene and 80 ml of water was added dropwise in 20 hours, with constant stirring, to a heated to 90° mixture of 500 g of butyl alcohol (b.p. 115°), 5 ml of sulfuric acid and 5 g of mercuric sulfate. Stirring at 90-100° was continued for 40 hours, and during this time another 30 g of mercuric sulfate was added in small portions. The product was neutralized with potash, filtered, the butyl alcohol vacuum-distilled on the water bath, and the residue extracted with ether, dried over sodium sulfate, and fractionally distilled. We obtained 108 g of a mixture of hydration products with b.p. 53-151° (18 mm) and n_D^{20} 1.4480. From the distilled butanol we isolated another 45 g of starting dienyne with b.p. 46-48° (50 mm) and n_D^{20} 1.4955. We took 203 g of the above-described mixture of hydration products, obtained from two similar experiments, and after fractional distillation in vacuo collected the following fractions: 1st, 86-88° (41 mm), n_D^{20} 1.4480, 33 g; 2nd, 95-97° (11 mm), n_D^{20} 1.4630, 45 g; 3rd, 111-112° (11 mm), n_D^{20} 1.4560, 15 g; 4th, 145-147° (11 mm), n_D^{20} 1.4350, 10 g. We also collected 63 g of intermediate fractions.

The first fraction was 2,5-dimethyltetrahydro-4-pyrone with some 1,3-dimethylcyclopentanone as impurity. The semicarbazone had m.p. 169.5-170.5°, and did not depress the melting point with an authentic specimen.

The second fraction, a pale-yellow liquid, was 2-butoxy-5-methyl-5-hexen-4-one (VII, R = C_4H_9).

B.p. 95-97° (11 mm), n_D^{20} 1.4630, d_4^{20} 0.9240, MR 54.83; calc. 54.20.

Found %: C 71.34, 71.12; H 10.90, 10.90. $C_{11}H_{20}O_2$. Calculated %: C 71.74; H 10.86.

The third fraction, a yellowish liquid, was 1-butoxy-2-methyl-4-hexen-3-one (VIII, R = C_4H_9).

B.p. 111-112° (11 mm), n_D^{20} 1.4560, d_4^{20} 0.9024, MR 55.00; calc. 54.20.

Found %: C 71.44, 71.07; H 10.99, 10.78. $C_{11}H_{20}O_2$. Calculated %: C 71.74; H 10.86.

The fourth fraction, a clear liquid, was 1,5-dibutoxy-5-methyl-3-hexanine (IX).

B.p. 145-147° (11 mm), n_D^{20} 1.4350, d_4^{20} 0.9105, MR 73.40; calc. 74.62.

Found %: C 70.27, 70.10; H 11.34, 11.65. $C_{15}H_{30}O_3$. Calculated %: C 70.30; H 11.72.

The butoxy ketones (VII, VIII, XI, R = C_4H_9) failed to give crystalline derivatives with 2,4-dinitrophenylhydrazine.

Reaction of methylamine with butoxy ketones (VII-IX). A mixture of 10 g of the butoxy ketone (b.p. 96-112° at 11 mm, n_D^{20} 1.4560), 25 g of a 24% aqueous methylamine solution and 30 ml of alcohol was heated in a glass ampoule on the boiling-water bath for four hours. The excess methylamine was distilled in vacuo (70 mm) on the water bath at 50°. The solution was acidified with dilute hydrochloric acid, and the neutral

products were extracted with ether. We obtained 3 g of butyl alcohol with b.p. 115°. The organic bases were salted out with potash, extracted with ether, dried over sodium sulfate, and vacuum-distilled. We obtained 3.2 g of 1,2,5-trimethyl-4-piperidone with b.p. 70-72° (7 mm), n_D^{20} 1.4563. The picrate had m.p. 161-162° (from alcohol), and did not depress the melting point with an authentic specimen [4].

Hydration of vinylisopropenylacetylene in methyl alcohol. Water (45 ml) was added dropwise in eight hours, with stirring, to a boiling mixture of 100 g of the dienyne (b.p. 51-53° at 43 mm, n_D^{20} 1.4949), 100 g of methyl alcohol, 3 ml of sulfuric acid and 3 g of mercuric sulfate, and during this time another 8 g of mercuric sulfate was added in small portions. At reaction end (8 hours) the odor of the dienyne had disappeared. The mixture was treated with 50 ml of water, and the reaction product was extracted with ether, washed with soda solution, dried over sodium sulfate, and fractionally distilled in vacuo. We obtained 86 g of mixed methoxy ketones with b.p. 64-97° (12 mm), n_D^{20} 1.4463 [1].

SUMMARY

1. Divinylacetylene and vinylisopropenylacetylene, when heated in aqueous solutions of ethanol, butanol and isopropyl alcohol in the presence of mercuric sulfate and sulfuric acid, suffer hydration to the corresponding dienones. Here divinylacetylene gives vinyl propenyl ketone, while vinylisopropenylacetylene gives propenyl isopropenyl ketone. The resulting dienones under the reaction conditions add either one or two molecules of the alcohol and are converted to the corresponding β-alkoxy ketones; the yield of these ketones decreases with increase in the molecular weight of the alcohol.

2. The hydration of divinylacetylene in either 50% methyl or ethyl alcohol gives 2-methyltetrahydro-4-pyrone as the solitary reaction product in a yield of 50%.

Alcohols add to dienones in such manner that the alkoxy group is always found in the β-position to the carbonyl group.

3. All of the β-alkoxy ketones synthesized by us are capable of reacting with primary and secondary amines to yield, depending on the reaction conditions, either 4-piperidones or β-amino ketones.

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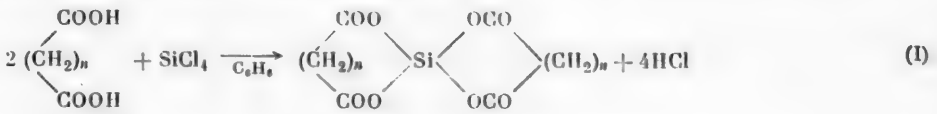
TETRAACYLOXYSILANES IN ORGANIC SYNTHESIS

XVIII. STRUCTURE OF THE SILICOANHYDRIDES OF DIBASIC SATURATED ORGANIC ACIDS

Iu.K. Iur'ev, Z.V. Beliakova and G.B. Eliakov

In previous papers we had shown that silicon tetrachloride reacts with dibasic saturated organic acids in a neutral solvent (benzene) with the liberation of hydrogen chloride and the formation of silicoanhydrides of the dibasic organic acids. The latter (silicoanhydrides) in the presence of aluminum chloride are capable of condensing with either benzene [1] or thiophene [2] to give the corresponding ω-benzoylalkylcarboxylic acids (yields 33-77%) or ω-(2-thenoyl)alkylcarboxylic acids (yields 56-96%). The possibility of obtaining keto acids of the selenophene series by such a procedure was established on the example of synthesizing β-(2-selenoyl)propionic acid [3].

However, in these papers the question of the structure of the silicoanhydrides of dibasic acids was left open. Based on general considerations, the structure of the silicoanhydride of a dibasic acid, formed under the indicated conditions, may be depicted by the following structural formulas.



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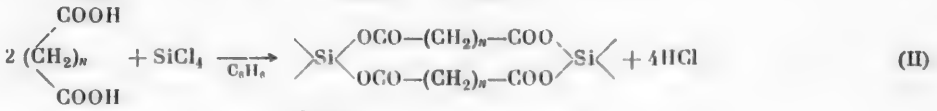

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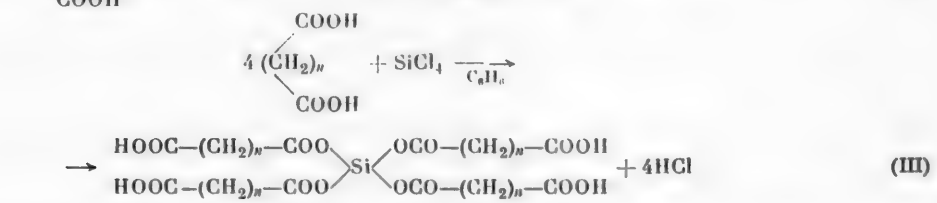

(III)

With respect to the experimental data obtained by us in the acylation of benzene and thiophene with the silicoanhydrides of saturated dibasic organic acids, it should be mentioned that the only reaction products obtained here were the keto acids, and not in a single case did we observe the secondary formation of diketones – symmetrical dibenzoyl- and di(2-thenoyl)-alkanes.

In contrast to this is the fact that, together with keto acids, diketones are always formed when the benzene ring is acylated with the carboxylic anhydrides of dibasic acids. Thus, the condensation of glutaric anhydrides with benzene in the presence of anhydrous aluminum chloride gives both γ-benzoylbutyric acid (24%) and α,γ-dibenzoylpropane (18.5%) [4]. For the condensation to go in the two indicated directions is even more characteristic for the anhydrides of the higher dibasic acids: when benzene was acylated with the polymeric anhydrides of adipic and sebacic acids $[\overset{\longrightarrow}{CO-(CH_2)_nCO}]_x$, besides the corresponding ω-benzoyl aliphatic acids, the corresponding diketones and dibasic acids were formed in a ratio that corresponded to the equation proposed by Hill [5], and, respectively, x/2 : x/4 : x/4.

In a similar manner, the acylation of thiophene with the polymeric anhydrides of the higher dibasic acids in the presence of anhydrous stannic chloride gave a mixture of reaction products, composed of the corresponding keto acid, diketone and dibasic acid [6].

The acylation of benzene with the acid chlorides of dibasic acids gives both keto acids and diketones, in which connection some of the keto acids are obtained only if the reactants are taken in a 1:1 molar ratio [7, 8]. When the reactants are taken in the ratio of 2 moles of benzene to 1 mole of acid chloride, the reaction goes entirely in the direction of forming the diketone.

The absence of diketones in the products of the acylation of benzene and thiophene with the silicoanhydrides of dibasic acids served as important, but not conclusive, evidence that these silicoanhydrides, formed in the medium of a neutral solvent, have the structure of (III). Since one-half as much hydrogen chloride should be liberated in the formation of structure (III) as in the formation of either structure (I) or (II) (based on the amount of dibasic acid taken for reaction), then, to answer the question as to the structure of the silicoanhydrides of dibasic acids, we ran a series of experiments on the preparation of silicosuccinic anhydride, in which the amount of hydrogen chloride liberated was determined.

The obtained results served as convincing evidence that structure (III) is valid: the amount of hydrogen chloride, liberated in the reaction of silicon tetrachloride with succinic acid in absolute benzene medium, corresponded to the formation of this structure.

The analysis results obtained for the formed silicosuccinic anhydride also speak in favor of structure (III): its average silicon content was 5.36% (5.31 and 5.41%), as compared to a theoretical value of 5.65% for structure (III). The calculated amount of silicon for structures (I) and (II) is 10.78%.

A comparison of the experimental data with the calculated, given in the Table, convincingly shows that the silicosuccinic anhydride, formed in the above-described manner from succinic acid and silicon tetrachloride, has the structure of (III), in which the free carboxyl groups in each of the four acid radicals, linked to the silicon atom, are retained.

Consequently, the structure of the silicoanhydrides of saturated dibasic acids is such that when they are used to acylate either the benzene or the thiophene ring under the conditions of the Gustavson–Friedel–Crafts reaction, only the corresponding keto acids are obtained, without the diketones as a by-product. Also, if substantial amounts of other silicoanhydride forms of the dibasic acid with the possible structures of (I) and (II) had been formed, then we would have observed the secondary formation of diketones, which, however, did not occur.

Conclusive proof of the structure of the silicoanhydrides of dibasic organic acids would also be the preparation of the acid esters of dibasic acids from them when reacted with an alcohol, or of the substituted monoamides of dibasic acids when reacted with amines. However, when silicosuccinic anhydride was reacted with anhydrous ethyl alcohol we obtained the diethyl ester of succinic acid, the formation of which is obviously associated with secondary processes.

Experiments on the preparation of a substituted monoamide of succinic acid by reacting diethylamine with silicosuccinic anhydride in benzene medium gave positive results: the mono-(N,N-diethyl)amide of succinic acid was obtained without the substituted diamide of this acid as by-product.

$$Si(OCOCH_2CH_2COOH)_4 + 4(C_2H_5)_2NH \rightarrow 4(C_2H_5)_2NCOCH_2CH_2COOH + Si(OH)_4$$

Consequently, the structure of the silicoanhydrides of dibasic acids is actually expressed by the (III) structure proposed by us.

EXPERIMENTAL

Preparation of silicosuccinic anhydride. The experiments were run in a three-necked flask (750 ml), fitted with a stirrer and an efficient reflux condenser, the latter closed with a stopper fitted with an outlet tube, connected to a wash bottle filled with anhydrous kerosene. The wash bottle was connected to two absorption flasks containing standard sodium hydroxide solution. A tube, descending to the bottom of the flask, was also inserted in the reaction flask, and a stream of dry air was passed through it in order to displace the reaction hydrogen chloride.

Expt. No.	Taken for reaction				Amount				Si (in %)		
	succinic acid		silicon tetrachloride		of hydrogen chloride (in g)		of sodium hydroxide, required to neutralize the hydrogen chloride (in g)		found	calculated for the formula of structure	
	in g	in g-mole	in g	in g-mole	found	calc.*	found	calc.*		(I) and (II) $C_8H_8O_4Si$	(III) $C_{16}H_{20}C_{16}Si$
1	5.9	0.05	4.25	0.025	2.09**	1.82	2.3**	2.0	--	--	--
2	5.9	0.05	2.12	0.0125	1.57	1.82	1.73	2.0	--	--	--
3	11.8	0.1	8.5	0.05	3.59	3.65	3.93	4.0	5.31 5.41	10.78	5.65

*Amount of hydrogen chloride in grams (and the amount of sodium hydroxide equivalent to it) calculated for the silicosuccinic anhydride having the formula of structure (III); these amounts are double for the case of structures (I) and (II).

**The high result is due to the use of too strong an air current, which carried out a small amount of silicon tetrachloride from the wash bottle containing kerosene; evidence of this was the appearance of turbidity in the first absorption flask containing standard sodium hydroxide solution.

Into the flask were charged 0.05-0.1 g-mole of succinic acid, 500 ml of absolute benzene and 0.0125-0.05 g-mole of silicon tetrachloride. The reaction mixture was heated on the water bath with constant stirring, first at 70-80°, and then on the boiling-water bath. The liberated hydrogen chloride was purified from traces of entrained silicon tetrachloride by passing through the wash bottle with kerosene,(in which the $SiCl_4$ is readily soluble) and then it was absorbed in the vessels containing the standard alkali. At the end of experiment (hydrogen chloride was no longer evolved) the contents of the absorption flasks were transferred to a volumetric flask, and the amount of sodium hydroxide consumed for the reaction was determined by titration with hydrochloric acid. The results, obtained in these experiments, are summarized in the Table.

In Expt. 3, on conclusion of reaction, the benzene and excess silicon tetrachloride were vacuum-distilled, and the residue was analyzed for silicon.

It should be emphasized that although a double amount of silicon tetrachloride was taken in Expt. 3, still the amount of hydrogen chloride liberated was approximately the same as that liberated in Expt. 2, where the silicon tetrachloride was taken in an equimolar amount, i.e., in the amount needed to form the silicoanhydride with structure (III).

For comparison we have given in the Table the calculated percent of silicon, which should correspond to each of the three possible formulas for the structure of the silicoanhydride of succinic acid.

Reaction of ethyl alcohol with silicosuccinic anhydride. A benzene solution of silicosuccinic anhydride, obtained as described above from 11.8 g (0.1 mole) of succinic acid and 3.5 ml (0.03 mole) of silicon tetrachloride in 400 ml of benzene, was distilled to remove 200 ml of benzene; then a stream of dry air was passed to remove any hydrogen chloride, after which the solution was cooled to room temperature, 4.6 g (0.1 mole) of anhydrous ethyl alcohol was added, and the whole was stirred for four hours. The silicic acid was filtered, the benzene was vacuum-distilled at 40-50°, and the residue was distilled. We obtained 2 g (26.5%) of diethyl succinate with b.p. 102-105° (14 mm). Literature: b.p. 103° (14 mm) [9].

Mono-(N,N-diethyl)amide of succinic acid. A benzene solution of silicosuccinic anhydride, obtained as described above from 11.8 g (0.1 mole) of succinic acid and 3.5 ml (0.03 mole) of silicon tetrachloride, was treated dropwise with 14.6 g (0.2 mole) of diethylamine, after which the mixture was heated for 5-6 hours on the water bath, first at 50-60°, and then on the boiling-water bath. After cooling, the silicic acid was filtered

and washed with hot acetone. The solvents were distilled off and the residue was vacuum-distilled. We obtained 7 g (44.5%) of product with b.p. 160° (7 mm), and m.p. 83-84° (from acetone). Literature: m.p. 82.1-84.1° [10].

Found %: C 55.82, 55.86; H 8.93, 8.99. Equiv. 174.4, 173.7. $C_9H_{15}O_3N$. Calculated %: C 55.49; H 8.73. Equiv. 173.2

SUMMARY

The reaction of a saturated dibasic organic acid with silicon tetrachloride in an inert solvent yields the silicoanhydride of the dibasic acid, in which the silicon atom is linked to four radicals of the dibasic acid with retention of a free carboxyl group in each radical.

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TETRAACYLOXYSILANES IN ORGANIC SYNTHESIS

XIX. SYNTHESIS OF 3- AND 4-NITROCINNAMIC ACIDS AND THEIR HOMOLOGS [α-ALKYL-β-(NITROPHENYL)ACRYLIC ACIDS]

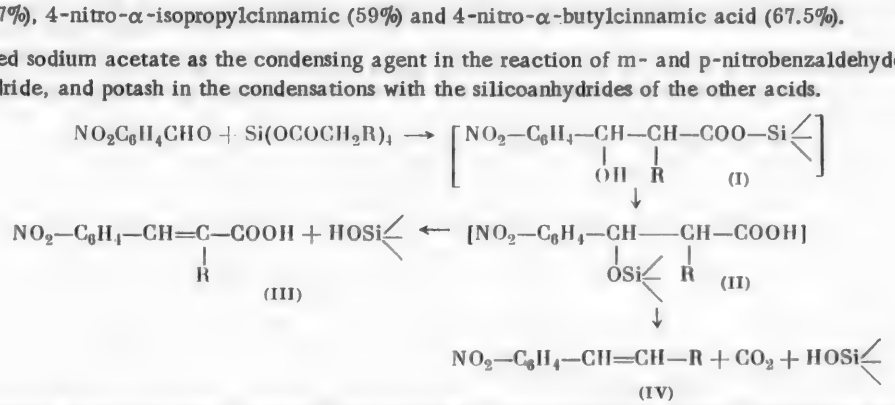
Iu.K. Iur'ev, A.N. Vysokosov and S.N. Godovikova

In previous papers two of us had shown that the mixed anhydrides of saturated monobasic organic acids and orthosilicic acid (tetraacyloxysilanes) will condense with benzaldehyde and other aldehydes of an aromatic character, like furfural and 2-thiophenecarboxaldehyde, to yield the corresponding α,β-unsaturated acids of the benzene [1], furan [2] and thiophene [2] series.

The preparation of cinnamic and 2-furylacrylic acids and their homologs by such a procedure, and also of 2-thienylacrylic acid (in high yields), is convincing evidence that the hydrogen atoms in the α-methylene groups of the silicoanhydrides of organic acids are no less labile than those found in the anhydrides of organic acids. Due to the strong electronegativity of the $\cdot Si(OCOCH_2R)_3$ radical, it is possible that the mobility of the hydrogen atoms in the methylene group of the silicoanhydrides of organic acids, $Si(OCOCH_2R)_4$, is even somewhat greater than in the anhydride of the same acid.

In this paper we condensed the silicoanhydrides of saturated monobasic organic acids with m- and p-nitrobenzaldehyde, and in this way obtained the following nitrocinnamic acids in high yields: 3-nitrocinnamic (83.5%), 4-nitrocinnamic (89.5%), 4-nitro-α-methylcinnamic (88%), 4-nitro-α-ethylcinnamic (87%), 4-nitro-α-propylcinnamic (47%), 4-nitro-α-isopropylcinnamic (59%) and 4-nitro-α-butylcinnamic acid (67.5%).

We used sodium acetate as the condensing agent in the reaction of m- and p-nitrobenzaldehyde with silicoacetic anhydride, and potash in the condensations with the silicoanhydrides of the other acids.



It should be emphasized that a similar behavior of the silicoanhydrides and the anhydrides of organic acids in the Perkin reaction is also manifested in the fact that when the condensation is run with the indicated nitrobenzaldehydes, as well as other nitrobenzaldehydes, the reaction in both cases goes to greater completion and leads to higher yields of the corresponding nitrocinnamic acid than is true for the unsubstituted cinnamic acids.

The stabilizing influence exerted by the nitro group in the carbonyl-containing reaction component is undoubtedly manifested in the intermediate stage of the reaction, where the ester of the orthosilicic and α-alkyl-β-(nitrophenyl)-β-hydroxyhydracrylic acids (II), formed from the addition product (I), loses silicic acid with the formation of the α-alkyl-β-(nitrophenyl)acrylic acid (III) more easily than it suffers decarboxylation and the cleavage of silicic acid with the formation of the nitrostyrene homolog (IV), the secondary product of this process.

In this connection it should be mentioned that when we condensed silicoisovaleric anhydride with p-nitrobenzaldehyde, both under mild conditions – at 100° for 20 hours, and under more drastic conditions – at 165-170°

Reaction components (in g)						Reaction conditions			Reaction products										
silicoanhydride									yield		constants and analysis data								
												% C		% H		% N		
name	amount	m-nitrobenzaldehyde	p-nitrobenzaldehyde	sodium acetate	potash	temperature	time of heating (in hours)	acid	in g	in %	melting point	found	calc.	found	calc.	found	calc.	Literature melting point
Silicoacetic	13.2	3.8	—	4.1	—	180—185°	12	3-Nitrocinnamic	4.0	83.5	200—201°*	—	—	—	—	—	—	200—201° [3]
»	26.4	—	7.55	8.2	—	180—185	12	4-Nitrocinnamic	8.6	89.5	287.5—288**	—	—	—	—	—	—	285—286° [4];
»	13.2	—	7.55	—	6.9	180—185	8	»	4.0	41.5	287.5—288**	—	—	—	—	—	—	287° [5]; 288° [3, 6]
Silicopropionic	12.0	—	3.78	—	5.2	165—170	15	4-Nitro-α-methylcinnamic	4.6	88.0	207.5—208	58.07, 58.02	57.97	4.45, 4.40	4.38	6.52, 6.67	6.76	208° [7, 8]
Silicobutyric	28.2	—	7.55	—	10.4	165—170	15	4-Nitro-α-ethylcinnamic	9.6	87.0	169—169.5	59.75, 59.89	59.71	5.07, 5.13	5.01	6.42, 6.39	6.33	168—169° [9]
Silicovaleric	11.0	—	3.78	—	3.75	165—170	15	4-Nitro-α-propylcinnamic	2.85	47.0	134—134.5	61.26, 61.21	61.27	5.51, 5.48	5.57	6.10, 6.17	5.96	132—134° [9]
Silicoisovaleric	22.0	—	7.56	—	7.0	100	20	4-Nitro-α-isopropylcinnamic	6.9	59.0	178—179	61.19, 61.22	61.27	5.58, 5.50	5.57	6.08, 6.13	5.96	Not described in the literature
»	22.0	—	7.56	—	7.0	165—170	10	»	4.2	36.0	178—179	—	—	—	—	—	—	Ditto
Silicocaproic	24.4	—	3.78	—	7.0	165—170	10	4-Nitro-α-butylcinnamic	4.2	67.5	162.5—163	62.21, 62.30	62.23	6.16, 6.20	6.18	5.39, 5.38	5.62	162—163° [9]

*The mixed melting point with authentic 3-nitrocinnamic acid was not depressed.

**The mixed melting point with authentic 4-nitrocinnamic acid was not depressed.

for 10 hours, we obtained 4-nitro-α-isopropylcinnamic acid in a yield of 59% and 36%, respectively. When we condensed the silicoisovaleric anhydride with benzaldehyde [1] the principal and solitary reaction product obtained by us was 1-phenyl-3-methyl-1-butene (α-phenyl-β-isopropylethylene) (70% yield).

EXPERIMENTAL

The tetraacyloxysilanes used in the present study were obtained by the earlier-described procedure [1].

A mixture of 0.05-0.025 g-mole of p-nitrobenzaldehyde, 0.05-0.025 g-mole of the silicoanhydride of the organic acid and 0.05-0.025 g-mole of either anhydrous sodium acetate or potash, contained in a 100-ml flask fitted with an air reflux condenser (connected to a calcium chloride tube) and stirrer, was heated in an oil bath (with thermometer) with good stirring.

The mixture after cooling was treated with 2 N sodium hydroxide solution until faintly alkaline (to litmus) [1], then diluted with water to a volume of 300-400 ml, heated to 80°, and filtered. The filtrate was acidified with concentrated hydrochloric acid (to litmus), then allowed to stand in the cold for 2-3 hours, and the nitrocinnamic acid separated and recrystallized from alcohol.

The results obtained by us are summarized in the Table.

SUMMARY

The condensation of the silicoanhydrides of saturated monobasic organic acids with m- and p-nitrobenzaldehyde in the presence of either sodium acetate or potash permits obtaining the corresponding nitrocinnamic acids in high yields, even in the case where the silicoanhydride is formed from an acid with a branched radical.

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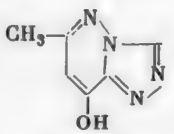
REACTIONS OF HYDRAZINE DERIVATIVES

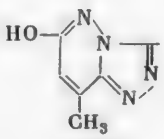
XIX. CONDENSATION OF 4-AMINO-[1,2,4]-TRIAZOLE WITH ESTERS

A.N. Kost and F. Gents

The heating of hydrazine with formic acid readily yields 4-amino-[1,2,4]-triazole [1]. Despite the presence of four nitrogen atoms, this amine is more acidic than basic [2]; however, the amino group in this compound is still capable of entering into various condensation reactions, at times with simultaneous involvement of the hydrogen atoms in the triazole ring (in positions 3 and 5). Thus, for example, even Bülow [3] showed that when the aminotriazole is heated with acetylacetone it suffers condensation, with the cleavage of water and the formation of 6,8-dimethyl-[1,2,4]-triazolo-(b)-pyridazine (I).* The reaction with acetoacetic ester goes in a similar manner, in which connection a compound is formed to which Bülow [5] has assigned the structure (IIa); in our opinion the compound has the more probable structure of 6-hydroxy-8-methyl-[1,2,4]-triazolo-(b)-pyridazine (IIb).



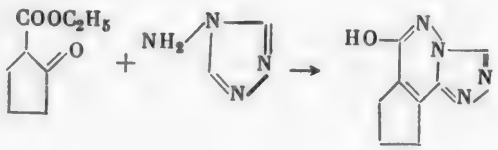
(IIa)



(IIb)

Methylacetoacetic and benzoylacetic esters react in a similar manner with the aminotriazole [6]. It should be mentioned that the reaction goes even at the boil when run in either alcohol or acetic acid solution, i.e., it goes with much greater ease than in the case, for example, of the condensation of aniline with acetoacetic ester to give 4-hydroxyquinaldine [7].

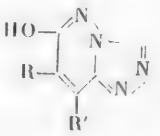
In view of the fact that hydroxytriazolopyridazines are capable of forming complexes with metal cations [5, 6], we became interested in them and synthesized a number of their class. For this the proper β-keto ester was mixed with the 4-aminotriazole and the mixture heated for 20-30 minutes at 180-200° (the reaction alcohol and water are removed by distillation). If the reaction was too vigorous, as, for example, was true in the case of 2-carbethoxycyclopentanone (with the formation of compound III), then xylene, toluene or benzene was added to the reactant mixture and the reaction alcohol and water slowly removed by azeotropic distillation. At times we added the hydrochloride of the aminotriazole to serve as condensing agent. It is interesting to mention that the yield depended greatly on the rate of heating. If the temperature was raised slowly, then much tar formation occurred.



(III)

*The systematic name [4] for this structure is "2,4-dimethyl-1,6,7,9-tetraazabicyclo-[5—9]-nonatetraene."

In the case of 2-carbethoxycyclohexanone we were unable to obtain a condensation product even under the mildest conditions. The reaction goes with much tar formation, in which connection water is the main cleavage product. It is possible that this is due to the large degree of enolization shown by the keto ester, since, according to Dieckmann [8], 2-carbethoxycyclopentanone contains 4% of the enol form, while in the case of 2-carbethoxycyclohexanone the content of the enol form reaches 76%. In support of this theory is the fact that succinylsuccinic ester, which is almost completely enolized [9], cleaves water even more easily, reacting with the aminotriazole apparently through the enolic hydroxyl. Tar formation is also very readily incurred when cleavage of the alcohol is attempted, either by direct heating (0.5 hour at 160-170°) or by refluxing in acetic acid. Such a result was obtained when we attempted to condense the aminotriazole with α-formylphenylacetic ester (2 hours, 170°). We were also unable to extend the reaction to γ-keto esters: only tar formation was observed when the aminotriazole was heated with the ethyl ester of cyclopentanone-2-acetic acid [10] for 25 minutes at 190-210°. The same thing occurred when the water was removed from the reactant mixture by azeotropic distillation with toluene.



(IV) R = C_2H_5, R′ = CH_3
(V) R = C_4H_9-n, R′ = CH_3
(VI) R = $C_6H_5CH_2$, R′ = CH_3
(VII) R = C_7H_7-n, R′ = C_7H_{11}-n.
(VIII) R = H, R′ = C_2H_5
(IX) R = C_6H_5, R′ = $C_6H_5CH_2$

Having obtained compounds (I-IX) in the indicated manner, we next condensed the aminotriazole with malonic ester, assuming that similar to aniline, which gives dihydroxyquinoline with malonic ester, the aminotriazole would form the dihydroxytriazolopyridazine. However, it proved that the malonic ester, even when taken in large excess, reacts (when heated) with two molecules of the aminotriazole, forming N,N′-bis-(1,2,4-triazol-4-yl)-malonamide (X). Cyclization products involving the hydrogen atoms of the triazole ring could not be found. The structure of diamine (X) was shown by its infrared absorption spectrum,* which revealed the presence of maxima at 1690 (corresponds to the C—O bond) and 3084 cm^{-1} (corresponds to the C—N bond in the amido group). An acetic acid solution of this amide in the presence of sodium acetate precipitates the ions Cu^{2+}, Ni^{2+} and Co^{2+} from water solution, but does not precipitate Al^{3+}, Cd^{2+}, Bi^{3+} and Th^{4+}. Not one of these cations is precipitated in alkaline medium (in the presence of tartrate buffer).

The reaction does not go as well with ethylmalonic ester, and here we obtained the N,N′-bis-(1,2,4-triazol-4-yl)-amide of ethylmalonic acid (XI) in a yield of only 15.2%. In the case of butylmalonic ester only traces of a compound with m.p. 255-258° was isolated, while in the case of the diethyl ester of diethylmalonic acid we were unable to make the condensation go even after heating for 20 hours at 190-200°.

R = H (X), C_2H_5 (XI).

(XII)

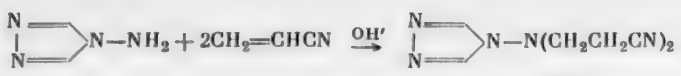
When the aminotriazole is reacted with diethyl oxalate it could be expected that the bicyclic compound would also be formed, but instead we obtained N,N′-bis-(1,2,4-triazol-4-yl)-oxamide (XII) in 54.1% yield. The infrared spectrum of this compound (maxima at 1698 and 3110 cm^{-1}) is similar to that of malonamide (X). A compound with m.p. 162-163.5° was isolated as a secondary product, but its structure was not determined.

Recently a paper was published in which it was stated that the oxalyldihydrazone of cyclohexanone is an extremely sensitive reagent for Cu^{2+} ions [11]. Based on a structural analogy, our diamide (XII) also precipitates Cu^{2+}, Mg^{2+} and Cd^{2+} ions in alkaline media containing tartrate buffer, and Cu^{2+} ions in a medium containing acetate buffer, but it does not precipitate Al^{3+} and Fe^{3+} ions. We propose to make a more detailed study of this compound as a test reagent for metal cations.

Continuing our study of the ability shown by the aminotriazole to condense, we found that under the usual conditions (boiling in the presence of either alkaline or acidic agents) it fails to react with methyl methacrylate, but with acrylonitrile, which is much more reactive, in the presence of alkali, it quite readily gives the dicyanoethylation product (XIII). In acid media or without catalysts the reaction does not go. It should be mentioned that up to now the cyanoethylation of amines, the NH_2 group of which is linked to a heterocyclic ring, has been

*The spectra were taken by B.V. Lokshin using an IKS-11 spectrophotometer (LiF prism).

unsuccessful [12]. In the present case the amino group functions not as an amine, but as an amide.



(XIII)

From the above-presented material it is obvious that under ordinary conditions the carbethoxy group acylates only the amino group of the aminotriazole, with practically no involvement of the hydrogen atoms in the ring. This makes it possible to state that the condensation of β-keto esters with the aminotriazole goes in such manner that the carbethoxy group also acylates the amino group, while the keto group cleaves the elements of water with involvement of the hydrogen atom in the 3 position of the triazole ring. Expressed differently, the reaction product has the structure of the 6-hydroxy-, and not of the 8-hydroxy-triazolopyridazine (corresponding to IIb, and not to IIa). We propose to obtain a more accurate answer to this problem through countersyntheses.

Bülow indicated that the triazolopyridazines are powerful poisons [3]. For this reason we sent a number of the compounds synthesized by us to the Department of Vertebrate Zoology at Moscow University, where the tests were run by N.M. Dukel'skaia. It was found that compounds (I, VI, X, XII and XIII), when administered "per os" (with food) to rats in three consecutive doses (in portions of 170-180 mg/kg of body weight), showed very little toxic effect. When administered intravenously to rabbits in a dose of 200 mg/kg it proved that compound (XIII) was toxic (breathing paralyzed), while compound (XII) in the same dosage was not poisonous. Consequently, the toxicity of the indicated compounds was slight.

EXPERIMENTAL

4-Amino-[1,2,4]-triazole. Into a two-liter flask, fitted with a reflux condenser and cooled externally with a stream of water, was charged 540 g of 85% formic acid, and then gradually (in 40 minutes), with occasional shaking, 780 g of 96% hydrazine hydrate was added. When brisk reaction had subsided the reflux condenser was replaced by a descending one, and the water and excess hydrazine were removed by distillation. The distillation began at a mixture temperature of 115°, and in five hours the temperature reached 200°. The mixture was kept at this temperature for four hours, then it was cooled, and a mixture of 750 ml of alcohol and 750 ml of ether was added. On standing in the refrigerator at −10°, the solution deposited white crystals of 4-amino-[1,2,4]-triazole, which were filtered, washed with ether, and dried in a vacuum-oven. We obtained 318 g (75.7%) of substance with m.p. 79-80° [1]. If the amount of reactants is reduced to 1/10 of that above, then the yield rises to 93-95%.

The dimethyltriazolopyridazine (I) was obtained when the aminotriazole was heated with acetylacetone [3]. In a similar manner, using the Bülow method [5], we synthesized the 6-hydroxy-8-methyltriazolopyridazine (II) from the aminotriazole and acetoacetic esters.

6-Hydroxy-8-methyl-7-ethyl-[1,2,4]-triazolo-(b)-pyridazine (IV). Into a round-bottomed flask, fitted with a thermometer that reached the reaction mixture, was charged 2.1 g of the 4-aminotriazole and 4 g of ethylacetoacetic ester with b.p. 75-78° (7 mm) and n_D^{20} 1.4212. The mixture was heated in a metal bath at 170°. A brisk boiling of the reaction mass began at this temperature and the water and alcohol began to distill. The mixture was kept at 170-190° for 30 minutes, then cooled, and finally dissolved in hot water. The crystals that deposited on cooling were filtered, washed with cold water, then with alcohol, and finally dried in a vacuum-oven. We obtained 1.2 g (27%) of 6-hydroxy-8-methyl-7-ethyl-[1,2,4]-triazolo-(b)-pyridazine. After four recrystallizations from 50% aqueous alcohol, m.p. 229-231° (decomp.).

Found %: C 54.12, 53.90; H 5.93, 5.86. $C_8H_{10}ON_4$. Calculated %: C 53.91; H 5.66.

6-Hydroxy-8-methyl-7-butyl-[1,2,4]-triazolo-(b)-pyridazine (V). A mixture of 4.2 g of the 4-aminotriazole and 10 g of butylacetoacetic ester with b.p. 107-108° (12 mm) and n_D^{20} 1.4270 was heated at 190-205° for 30 minutes. The crystalline mass obtained on cooling was dissolved in hot acetic acid, and the deposited crystals of 6-hydroxy-8-methyl-7-butyl-[1,2,4]-triazolo-(b)-pyridazine were filtered and air-dried. Yield 6.1 g (59.2%). After two recrystallizations from 75% acetic acid, m.p. 206°.

Found %: N 27.08, 27.46. $C_{10}H_{14}ON_4$. Calculated %: N 27.17.

6-Hydroxy-8-methyl-7-benzyl-[1,2,4]-triazolo-(b)-pyridazine (VI). A mixture of 8 g of the 4-aminotriazole and 21.2 g of benzylacetoacetic ester with b.p. 116-117° (1 mm) and n_D^{20} 1.4983 was heated rapidly to 180°. In seven minutes at 180-190° the mixture became homogeneous (the alcohol and water had distilled); then the temperature was raised to 190-200°, and in ten minutes the reaction mass swelled up and crystallized. The flask contents were dissolved in hot glacial acetic acid, and after the usual technique of cooling, filtering, washing and drying in a vacuum-oven we obtained 9.2 g (40%) of 6-hydroxy-8-methyl-7-benzyl-[1,2,4]-triazolo-(b)-pyridazine. After two recrystallizations from glacial acetic acid, m.p. 212° (decomp.).

Found %: C 64.87, 65.05; H 5.20, 5.28. $C_{13}H_{12}ON_4$. Calculated %: C 64.97; H 5.04.

6-Hydroxy-7-butyl-8-amyl-[1,2,4]-triazolo-(b)-pyridazine (VII). The Claisen condensation of 0.2 mole of methyl caproate with 0.1 mole of sodium methylate gave 9.7 g (42.5%) of methyl caproylcaproate, b.p. 122-123° (2 mm), n_D^{20} 1.4335. One gram of the 4-aminotriazole and a few crystals of the 4-aminotriazole hydrochloride were added to 3 g of this ester. The mixture was heated at 185-195° for 30 minutes; the crystals obtained on cooling were dissolved in hot alcohol, precipitated by the addition of water, washed with alcohol, then with water, and finally dried in a vacuum-oven. We obtained 0.6 g (18.3%) of 6-hydroxy-7-butyl-8-amyl-[1,2,4]-triazolo-(b)-pyridazine. After four recrystallizations from 50% aqueous alcohol, m.p. 169.5-170.5°.

Found %: C 63.71, 63.95; H 8.66, 8.70. $C_{14}H_{22}ON_4$. Calculated %: C 64.09; H 8.46.

6-Hydroxy-8-ethyl-[1,2,4]-triazolo-(b)-pyridazine (VIII). A solution of 80 g of freshly distilled malonic ester in 50 ml of anhydrous ethanol was added to a suspension of 12.5 g of magnesium in 50 ml of anhydrous ethanol and 0.5 ml of carbon tetrachloride. The mixture was heated cautiously on the water bath until hydrogen began to evolve. When the reaction had subsided somewhat, 150 ml of dry ether was added, and the mixture was heated under reflux until all of the magnesium had dissolved (about seven hours). The solution was cooled and then a solution of 49 g of propionyl chloride in 50 ml of anhydrous ether was added gradually, after which the mixture was heated under reflux for another hour. The mixture after cooling was decomposed with 350 ml of 2 N sulfuric acid, then with water, dried over magnesium sulfate, and the ether removed by vacuum-distillation. The residue was treated with 8 g of β-naphthalenesulfonic acid monohydrate, and then the mixture was slowly heated under air reflux to 200° (gas began to evolve at 130°). After heating for five hours the gas evolution ceased, and the mixture was cooled, diluted with ether, washed three times with soda solution, then twice with water, and the water extracts extracted with ether. The combined ether extracts were dried over magnesium sulfate, the ether was distilled off, and the residue was vacuum-distilled. We obtained 20.6 g (34.5%) of the propionylacetate, b.p. 67-72° (5 mm), n_D^{20} 1.4230 [13].

A mixture of 2.1 g of the 4-aminotriazole and 4.3 g of the above keto ester was heated for 1.5 hours at 160-170°. The crystals obtained on cooling were dissolved in hot glacial acetic acid and then reprecipitated by the addition of water. After filtration, washing with water and drying in the air we isolated 1.6 g (39%) of 6-hydroxy-8-ethyl-[1,2,4]-triazolo-(b)-pyridazine. After two recrystallizations from 30% acetic acid, m.p. 236.5-237.5°.

Found %: C 51.17, 51.37; H 5.09, 5.10. $C_7H_8ON_4$. Calculated %: C 51.21; H 4.91.

6-Hydroxy-7-phenyl-8-benzyl-[1,2,4]-triazolo-(b)-pyridazine (IX). Ethyl phenylacetate (0.15 mole) was added gradually, with cooling, to an ether solution of 0.25 mole of isopropylmagnesium bromide. When gas (propane) evolution had ceased the mixture was allowed to stand at room temperature for two hours, then 200 ml of ether was added, and the mixture decomposed with 2 N sulfuric acid and ice. The ether layer was washed with water, then with sodium bicarbonate solution, again with water, and finally it was dried over magnesium sulfate. Most of the ether was evaporated, and the resulting crystals were filtered, washed with alcohol, and air-dried. We obtained 13.5 g (61.5%) of the α,γ-diphenylacetoacetic ester with m.p. 77-78° [14].

A solution of 4 g of the above ester and 1 g of the 4-aminotriazole in 20 ml of glacial acetic acid was heated under reflux for 46 hours. Then the acetic acid was removed by vacuum-evaporation on the water bath, and the residual oil was treated with water. Colorless crystals separated after standing for a day, which were filtered, washed with ether, and vacuum-dried. We obtained 0.3 g (8.3%) of 6-hydroxy-7-phenyl-8-benzyl-[1,2,4]-triazolo-(b)-pyridazine. After recrystallization from 70% acetic acid, m.p. 286-290°. An attempt to run the reaction at 180-200° (0.5 hour) without solvent led to pronounced tarring.

Found %: C 71.59, 71.66; H 4.78, 4.83. $C_{18}H_{14}ON_4$. Calculated %: C 71.51; H 4.67.

6-Hydroxy-7,8-trimethylene-[1,2,4]-triazolo-(b)-pyridazine (III). Into a Wurtz flask was charged 2.1 g of the 4-aminotriazole, 4.7 g of 2-carbethoxycyclopentanone and 60 ml of dry xylene. The mixture was heated slowly, the reaction alcohol and water being removed by azeotropic distillation with the xylene. When about 10 ml of liquid remained in the flask, it was treated with another 60 ml of xylene, and the distillation repeated. The dark residue, which crystallized on cooling, was dissolved in glacial acetic acid, the crystals reprecipitated by the addition of water, after which they were filtered, washed with alcohol, then with water, and finally vacuum-dried. We obtained 1.95 g (45.4%) of substance (III), which was purified by recrystallization from water with the addition of activated carbon. The colorless crystals obtained in this manner decomposed when heated above 250° and melted with strong decomposition at 292-295°.

Found %: C 54.35, 54.50; H 4.82, 4.95. $C_9H_8ON_4$. Calculated %: C 54.54; H 4.57.

N,N'-Bis-(1,2,4-triazol-4-yl)-malonamide (X). A mixture of 8.4 g of the 4-aminotriazole and 50 ml of malonic ester was heated in a Wurtz flask immersed in an oil bath. Frothing and the distillation of alcohol began at 170°. In 20 minutes at 170-180° the whole mass solidified. It was cooled, and the crystals after washing with alcohol and ether were dried in a vacuum-desiccator over phosphorus pentoxide. We obtained 7.2 g (61%) of diamide (X). After two recrystallizations from water, m.p. 265-270° (decomp.).

Found %: N 47.11, 47.38. $C_7H_8O_2N_8$. Calculated %: N 47.46.

N,N'-Bis-(1,2,4-triazol-4-yl)-amide of ethylmalonic acid (XI). A mixture of 16 ml of ethylmalonic ester and 4.2 g of the 4-aminotriazole was heated at 190-200° for 30 minutes. The mixture after cooling was treated with 30 ml of acetone, and after a day the crystals were separated by filtration, washed with water, and vacuum-dried. We obtained 1.0 g (15.2%) of diamide (XI), which after recrystallization from a mixture of anhydrous ethanol and glacial acetic acid (3:1), and then from 50% ethanol, had m.p. 247-248° (decomp.).

Found %: N 42.11, 42.10. $C_9H_{12}O_2N_8$. Calculated %: N 42.41.

N,N'-Bis-(1,2,4-triazol-4-yl)-oxamide (XII). A mixture of 17 g of the 4-aminotriazole and 58.4 g of diethyl oxalate was heated at 150-170° for 40 minutes, then cooled, treated with hot alcohol, and the crystals separated. After washing with alcohol, then with water and drying in a vacuum-oven we obtained 12 g (54.1%) of diamide (XII). The substance was purified by repeated precipitation from aqueous alkaline solution with acetic acid. The pure compound did not melt up to 360°, is soluble in chloroform, ether, benzene and dioxane, is very difficultly soluble in alcohol, water and glacial acetic acid, and is readily soluble in dilute aqueous alkali solutions.

Found %: N 50.41, 50.86. $C_6H_6O_2N_8$. Calculated %: N 50.44.

The alcohol solution on cooling deposited 0.4 g of yellowish needle crystals. After recrystallization from alcohol, m.p. 162-163.5°. Found %: C 45.46, 45.47; H 5.83, 5.87. The Lassaigne test for nitrogen was positive. The substance is readily soluble in water and in hot alcohol, and is insoluble in ether. Its structure was not investigated in greater detail.

4-(Di-β-cyanoethyl)-amino-[1,2,4]-triazole (XIII). Acrylonitrile (5.3 g) was added dropwise at room temperature to a solution of 8.4 g of the 4-aminotriazole and 0.1 g of sodium hydroxide in 200 ml of tert-butyl alcohol. Heat was evolved and the mixture turned red, after which crystals began to form. The reaction mass was heated for ten minutes on the water bath, and the crystals obtained on cooling were separated, washed with alcohol, and vacuum-dried. We obtained 7.1 g (74.8%) of dinitrile (XIII). After two recrystallizations from a mixture of alcohol and ether (3:1), m.p. 168-169°. The substance is readily soluble in water and hot alcohol, difficultly soluble in benzene, and very difficultly soluble in petroleum ether and chloroform.

Found %: C 50.63, 50.78; H 5.33, 5.68. $C_8H_{10}N_6$. Calculated %: C 50.51; H 5.30.

SUMMARY

1. We synthesized a number of 6-hydroxy-[1,2,4]-triazolo-(b)-pyridazines by the condensation of 4-amino-[1,2,4]-triazole with β-keto esters.

2. It was shown that diethyl oxalate and malonic ester do not react with the aminotriazole to give bicyclic compounds of the dihydroxytriazolopyridazine type, but instead give the corresponding ditriazolyldiamides.

3. The cyanoethylation of 4-aminotriazole, proceeding in alkaline medium, was described.

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REACTION OF ARYLSULFONAMIDES WITH PROPYLENE OXIDE

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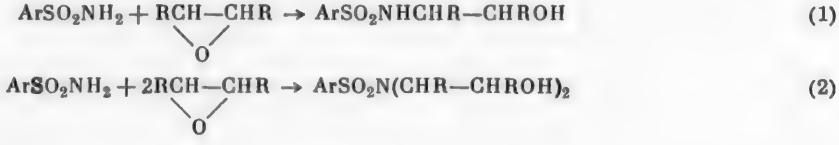
Ethylene oxide has found wide use as a raw material for the preparation of a multitude of products, used as solvents [1], plasticizers [2], lacquers [3], and in the production of explosives, poisons and medicinals [4].

The purpose of the present investigation was to study the reaction of propylene oxide with arylsulfonamides. This reaction is mentioned in the literature in a paper by Johnson [5], who reacted styrene oxide with p-toluenesulfonamide and isolated two products:

The reaction was studied by us for the case of propylene oxide and the three arylsulfonamides: benzenesulfonamide, p-chlorobenzenesulfonamide and p-toluenesulfonamide. Based on the general reaction scheme for the addition of olefin oxides to the NH_2 group, and the structure of the products isolated by Johnson, it is possible to postulate that the reaction goes in two stages. Consequently, depending on the reaction conditions, it is possible to obtain either mono- or disubstituted arylsulfonamides.

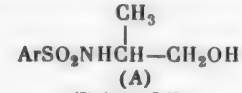


We ran the reaction in an autoclave at a pressure of 15-25 atm in the presence of sodium hydroxide as catalyst. It proved that in the case of benzenesulfonamide the main reaction product under these conditions is N-(β-hydroxyisopropyl)benzenesulfonamide (I). In the case of p-toluenesulfonamide and p-chlorobenzenesulfonamide, the reaction goes according to schemes 1 and 2 with the formation of the corresponding substituted amides.

From the literature it is known that certain products, similar to those obtained by us, were synthesized by the condensation of the sodium derivative of p-toluenesulfonamide with ethylene chlorohydrin [6].

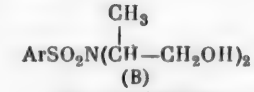
The N-(β-hydroxyisopropyl)arylsulfonamides (A) are sirupy, noncrystallizing liquids that cannot be vacuum-distilled without decomposition, and are soluble in aqueous alkali solutions, benzene, ether and alcohol. They were purified by conversion to the corresponding sodium derivatives, which were obtained as crystalline compounds with several molecules of crystallization water, and proved to be insoluble in organic solvents. The crystallization water was lost when the compounds were heated in vacuo at 120-130°.

The N-(β,β'-dihydroxydiisopropyl)arylsulfonamides (B) are colorless crystalline compounds, insoluble in alkalies, and soluble in hot carbon tetrachloride and petroleum ether.



(A)

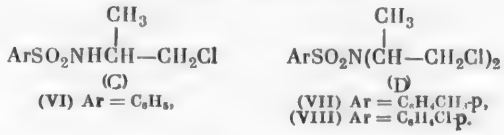
(I) Ar = C_6H_5,
(II) Ar = $C_6H_4CH_3$-p,
(III) Ar = C_6H_4Cl-p,



(B)

(IV) Ar = $C_6H_4CH_3$-p,
(V) Ar = C_6H_4Cl-p.

To confirm the structure of the obtained compounds we studied some of their chemical properties. The products obtained by the halogenation and acylation of the hydroxyl group were synthesized. We used thionyl chloride and phosphorus pentachloride to replace the hydroxyl group by chlorine. Here we obtained colorless crystalline products (C) and (D), which could be titrated with aqueous alkali solutions, and were soluble in ether, benzene, alcohol, hot petroleum ether and carbon tetrachloride.



(C)
(VI) Ar = C_6H_5,

(D)
(VII) Ar = $C_6H_4CH_3$-p,
(VIII) Ar = C_6H_4Cl-p.

For the acylation we used acetyl chloride. Only the N-(β-hydroxyisopropyl)benzenesulfonamide was acylated. The acylation product isolated from the reaction was a sirup, which could not be vacuum-distilled, and titrated as one equivalent in the presence of phenolphthalein.

EXPERIMENTAL

Reaction of propylene oxide with arylsulfonamides. A mixture of the arylsulfonamides (benzenesulfonamide 31.4 g, p-toluenesulfonamide 34.8 g, p-chlorobenzenesulfonamide 38.3 g), 17.4 g of propylene oxide, 0.1 g of NaOH and 200 ml of benzene was heated in an autoclave with stirrer for two hours. A temperature of 200-220° and a pressure of 20 atm was used for the benzenesulfonamide, 240-260° and 25 atm for the p-toluenesulfonamide, and 160-180° and 15 atm for the p-chlorobenzenesulfonamide. The reaction mixture was unloaded from the autoclave after cooling (in 15-20 hours). In the case of benzenesulfonamide, the benzene was vacuum-distilled from the reaction mixture, and the residue dissolved in 10% caustic solution and precipitated by acidification with concentrated hydrochloric acid. The obtained oil was separated, washed with water, and then dissolved in benzene. The benzene solution was dried over sodium sulfate and the benzene was removed by vacuum-distillation. In the case of p-toluenesulfonamide and p-chlorobenzenesulfonamide, a crystalline precipitate deposited from the reaction mixture, which was separated and treated with hot 10% caustic solution. The insoluble portion was recrystallized from either water or carbon tetrachloride. The mother liquor was worked up in the same manner as described above for benzenesulfonamide. In this manner we obtained:

N-(β-hydroxyisopropyl)benzenesulfonamide (I) in 58% yield, N-(β-hydroxyisopropyl)-p-toluenesulfonamide (II) in 15% yield, N-(β-hydroxyisopropyl)-p-chlorobenzenesulfonamide (III) in 5% yield, and N-(β,β'-dihydroxydiisopropyl)-p-toluenesulfonamide (IV) in 60% yield.

M.p. 126-128° (from water), colorless crystals.

Analysis of (IV).

Found %: N 4.45, 4.88. $C_{13}H_{21}O_4NS$. Calculated %: N 4.85.

N-(β,β'-Dihydroxydiisopropyl)-p-chlorobenzenesulfonamide (V), yield 48.2%, m.p. 107-110° (from carbon tetrachloride).

Found %: N 4.77. $C_{12}H_{18}O_4NClS$. Calculated %: N 4.56.

The reaction of p-toluenesulfonamide with propylene oxide can be made to go with a predominant formation of the monosubstituted derivative. For this a mixture of propylene oxide and benzene (1:1) is used as the solvent and the catalyst is omitted. The reaction mixture is worked up the same as described above. The yield of N-(β-hydroxyisopropyl)-p-toluenesulfonamide (II) in this case was 51%.

Preparation of sodium derivatives of N-(β-hydroxyisopropyl)-arylsulfonamides. To obtain the same derivatives, 5 ml portions of 10% sodium hydroxide solution were added in the cold to 0.01 mole of compounds (I)-(III). The obtained precipitates were filtered and washed with benzene.

Sodium derivative of (I), m.p. 54-56°.

Found %: S 9.72. $C_6H_5SO_2N(CHCH_2OH)Na \cdot 5H_2O$. Calculated %: S 9.78.

After heating in vacuo at 120-130°.

Found %: N 6.52. $C_9H_{12}O_3NSNa$. Calculated %: N 5.92.

Sodium derivative of (II), m.p. 64-66°.

Found %: S 8.56. $p\text{-}CH_3C_6H_4SO_2N(\overset{CH_3}{\overset{|}{C}}HCH_2OH)Na \cdot 7H_2O$. Calculated %: S 8.50.

After heating in vacuo at 120-135°.

Found %: N 6.03. $C_{10}H_{14}O_3NSNa$. Calculated %: N 5.57.

Sodium derivative of (III), m.p. 60-62°.

Found %: N 3.40. $p\text{-}ClC_6H_4N(\overset{CH_3}{\overset{|}{C}}HCH_2OH)Na \cdot 7H_2O$. Calculated %: N 3.44.

Preparation of halo derivatives. 1) Reaction of (I) with phosphorus pentachloride. To 4.3 g of the substance, contained in a small flask fitted with a reflux condenser, was added 5.2 g of phosphorus pentachloride. The reaction went violently with the evolution of heat. When the frothing had ceased the reaction mixture was heated on the boiling-water bath for 1.5 hours. At the end of heating the phosphorus oxychloride was vacuum-distilled. To identify the phosphorus oxychloride it was redistilled at atmospheric pressure, b.p. 103-106° (uncorrected). The yield of phosphorus oxychloride was 0.8 g. The residue from the distillation was extracted with ether, the ether vacuum-distilled, and the residue allowed to crystallize. In one to two days the crystalline product was freed from an oily impurity by pressing on porous plate. The yield of crude N-(β-chloroisopropyl)benzenesulfonamide was 2.5 g (53.7%), m.p. 75-77° (from petroleum ether).

Found %: Cl 15.2. $C_9H_{12}O_2NClS$. Calculated %: Cl 15.38.

2) Reaction of (IV) and (V) with thionyl chloride. To 1.43 g of substance (IV) or 1.5 g of substance (V), contained in a small flask fitted with a reflux condenser, was added 1.4 g of thionyl chloride. The reaction mixture was heated at 80-85° for two hours (until hydrogen chloride ceased to evolve). After reaction end, the mixture on cooling crystallized. In the case of substance (IV) the mixture was dissolved in carbon tetrachloride, the carbon tetrachloride was vacuum-distilled, and the residue was recrystallized from petroleum ether. In the case of substance (V) the residue was recrystallized from heavy gasoline.

N-(β,β'-Dichlorodiisopropyl)-p-toluenesulfonamide (VII) was obtained in 38.2% yield, m.p. 83-87°.

Found %: Cl 22.32. $C_{13}H_{19}O_2NCl_2S$. Calculated %: Cl 21.6.

N-(β,β'-Dichlorodiisopropyl)-p-chlorobenzenesulfonamide (VIII) was obtained in 43.5% yield, m.p. 85-88°.

Found %: Cl 29.8. $C_{12}H_{16}O_2NCl_3S$. Calculated %: Cl 30.7.

Acylation of N-(β-hydroxyisopropyl)benzenesulfonamide. A mixture of 6.9 g of substance (I) and 2.4 g of acetyl chloride was heated on the boiling-water bath for two hours. The reaction mixture was poured into water, and the lower layer separated and washed with water. The residual oil was dissolved in benzene, dried, and the benzene vacuum-distilled. The residue was a sirup which could not be vacuum-distilled and could be titrated with alkali solution.

N-(β-Acetoxyisopropyl)benzenesulfonamide, $C_6H_5SO_2NHCH(CH_3)CH_2OCOCH_3$, was obtained in 65% yield.

Found: equiv. (titration with NaOH in the presence of phenolphthalein) 0.982. Calculated: equiv. 1.

SUMMARY

1. The reaction of propylene oxide with arylsulfonamides was studied.

2. Eight new arylsulfonamide derivatives were synthesized and characterized.

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STUDY OF THE ISOMERIZATION AND DIMERIZATION OF DIMETHYLVINYLCARBINOL AS A FUNCTION OF THE pH OF THE REAGENT

IV. THE STRUCTURE OF A NEW ISOMER OF GERANIOL

A.I. Lebedeva and L.V. Kukhareva

Earlier [1] in studying the relationship between the yield of terpene alcohols and the pH of the reagent we examined the reaction of aqueous $KHSO_4$ solution with dimethylvinylcarbinol. Here a mixture of products was obtained which was not characterized completely.

This investigation was continued in the present paper; here we were able to isolate three other pure compounds, two of which proved to be identical with the unsaturated ethers obtained earlier [2], while the third was geraniol hydrate. It was shown by Pfau and Plattner [3] that the cleavage of the first molecule of water from primary-tertiary glycols, to which class geraniol hydrate belongs, occurs at the tertiary hydroxyl and the hydrogen atom found in the γ-position to the primary hydroxyl group. They assumed the structure of the terpene alcohol obtained in this manner to be identical with that of isogeraniol [4]. We dehydrated geraniol hydrate in a vacuum, with traces of $KHSO_4$, and obtained a terpene alcohol with the empirical formula $C_{10}H_{18}O$, differing in its constants from those of geraniol and linalool. When the alcohol was oxidized with chrome mixture we obtained an aldehyde, which gave a semicarbazone with m.p. 205-206°. Two moles of hydrogen were absorbed when the alcohol was hydrogenated over Pt. The saturated alcohol obtained here was identical with tetrahydrogeraniol. Ozonolysis of the $C_{10}H_{18}O$ alcohol gave, together with acetone, about 40% of formaldehyde and about 25% of formic acid. The infrared spectrum of the alcohol showed absorption bands at 837 and 890 cm^{-1}, characteristic for the "out-of-plane" C–H deformations in the groups $\begin{matrix} R_1 \\ R_2 \end{matrix}\!\!>\!C = CH - R_3$ and $\begin{matrix} R_1 \\ R_2 \end{matrix}\!\!>\!C = CH_2$, respectively. Especially characteristic was the band at 890 cm^{-1}, usually ascribed to a terminal methylene group [5]. The spectrum also showed an intense band at 1038 cm^{-1}, probably associated with the C–O vibrations in the CH_2OH group, and a band of valence vibrations (~3350 cm^{-1}).

When the $C_{10}H_{18}O$ alcohol was subjected to catalytic hydrogenation over $Pd/CaCO_3$, a halt was observed after the addition of 1 mole of hydrogen. The $C_{10}H_{20}O$ alcohol isolated as a result of the selective hydrogenation had physical constants that corresponded to those of citronellol. When the alcohol was oxidized with chrome mixture we obtained citronellic acid and its lactone, characterized as the silver salt. In its character the infrared absorption spectrum of the $C_{10}H_{20}O$ alcohol resembled that of β-citronellol, taken in the same wavelength region [6].

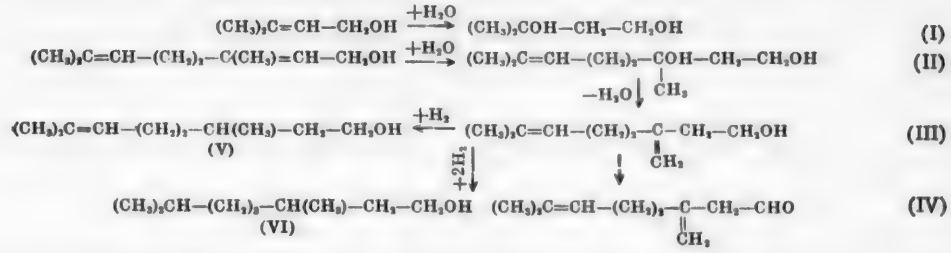
Both the absorption spectrum of β-citronellol and that of our investigated $C_{10}H_{20}O$ alcohol completely failed to show any evidence of a band at 890 cm^{-1}. Based on our studies, it can be stated that the following transformations are observed when dimethylvinylcarbinol is reacted with aqueous $KHSO_4$ solution.

1. Allylic rearrangement, leading to the formation of an equilibrium mixture of primary and tertiary alcohols.

2. Intramolecular dehydration, leading to the formation of isoprene, and intermolecular dehydration, leading to the formation of unsaturated ethers of dimethylvinylcarbinol and γ,γ-dimethylallyl alcohol.

3. Dimerization.

4. Hydration of monomeric and dimeric alcohols with the respective formation of α,α-dimethyltrimethylene glycol (I) and geraniol hydrate (II), giving on subsequent dehydration the terpene alcohol $C_{10}H_{18}O$ (III).



The fact that the infrared spectrum shows a strong absorption band at 890 cm^{-1}, that ozonolysis gives formic acid in a higher than 60% yield (total), that oxidation gives the $C_{10}H_{16}O$ aldehyde (IV), that selective hydrogenation yields β-citronellol (V), and that exhaustive hydrogenation gives tetrahydrogeraniol (VI), all make it possible to assume that the cleavage of the first molecule of water from geraniol hydrate goes at least 60% with involvement of the tertiary hydroxyl group and the hydrogen of the methyl group. The main terpene alcohol obtained here is 7-methyl-3-methylene-6-octenol (III).

That the methylmethyleneoctenol is obtained as the main product in the dehydration of geraniol hydrate once again emphasizes the fact that geraniol hydrate is not an intermediate product in the interconversions of terpene alcohols [7] or in the transformations of linalool to terpineol [8].

EXPERIMENTAL

For each experiment we took 200 g of 75% dimethylvinylcarbinol and 200 ml of 20% aqueous $KHSO_4$ solution. The operating technique was the same as that used earlier [9]. The upper layer was distilled. Here the following fractions were collected: from 35 to 145°, 58.9 g (isoprene, dimethylvinylcarbinol, γ,γ-dimethylallyl alcohol); from 50 to 75° (5 mm), 19.3 g (γ,γ-dimethylallyl ether of dimethylvinylcarbinol, γ,γ-dimethylallyl ether of γ,γ-dimethylallyl alcohol); from 75 to 120° (10 mm), 15.3 g (linalool, geraniol); from 120 to 145° (7 mm), 13.4 g; residue 2.7 g. From the ether extract of the lower layer we obtained 22.4 g of mixed dimethylvinylcarbinol and γ,γ-dimethylallyl alcohol, and 2.3 g of α,α-dimethyltrimethylene glycol (see the Table).

Redistillation of the fraction with b.p. 120-145° (7 mm) gave geraniol hydrate (II) (the data are given in the Table).

Compound	Name	Empirical formula	Boiling point (pressure in mm)	d_4^{20}	n_D^{20}	MR_D found	MR_D calc.	H^+	Literature reference
(I)	α,α-Dimethyltrimethylene glycol	$C_5H_{12}O_2$	92—92.5° (5)	0.9649	1.4425	28.57	28.34	1.98	[1]
(II)	Geraniol hydrate	$C_{10}H_{20}O_2$	133—134 (6)	0.9436	1.4689	50.84	50.96	1.96	[3]
(VII)	3,7-Dimethyl-1,3-octanediol	$C_{10}H_{22}O_2$	127—128 (5)	0.9099	1.4475	51.14	51.43	1.98	
(III)	7-Methyl-3-methylene-6-octenol	$C_{10}H_{18}O$	68—68.5 (2) 86—87 (5)	0.8776	1.4684	48.88	48.97	0.98	[3]
(VI)	Tetrahydrogeraniol	$C_{10}H_{22}O$	95—96 (9)	0.8402	1.4391	49.55	49.90	1.06	[11,12]
(V)	Citronellol	$C_{10}H_{20}O$	82—84 (4)	0.8552	1.4465	48.75	49.43	1.03	[12]

For hydrogenation we took 2.0 g of geraniol hydrate (II), 0.2 g of Pt and 40 ml of ether. The amount of hydrogen absorbed was 262 ml (100.5%). After distilling off the ether we obtained 1.5 g of 3,7-dimethyl-1,3-octanediol (VII) (see Table).

Geraniol hydrate (II) (11.0 g) was slowly distilled in vacuo in the presence of 0.05 g of $KHSO_4$ at 85-90° (5 mm). We obtained 8.4 g of substance, which was fractionally distilled through a column.

Found %: C 77.71; H 11.83. M 153.0. Calculated %: C 77.87; H 11.76. M 154.2. (Other data are given in the Table.)

For hydrogenation we took 1.75 g of 7-methyl-3-methylene-6-octenol (III), 0.3 g of Pt and 40 ml of alcohol. The amount of H_2 absorbed was 495 ml (97.0%). We obtained 1.2 g of tetrahydrogeraniol (VI).

Chrome mixture (2 g of $Na_2Cr_2O_7$, 3 g of H_2SO_4 and 9 ml of H_2O) was added with cooling and shaking to 3.1 g of 7-methyl-3-methylene-6-octenol (III). Then the mixture was heated for 15 minutes at 60-70°, diluted with water, and neutralized with $NaHCO_3$. The neutral compounds were steam-distilled and then extracted with ether. We obtained 1.3 g of aldehyde (IV), giving the silver-mirror test. The semicarbazone had m.p. 205-206° (from alcohol).

Found %: C 63.07; H 9.32; N 20.24. $C_{11}H_{19}ON_3$. Calculated %: C 63.14; H 9.15; N 20.07.

A solution of 2.5 g of 7-methyl-3-methylene-6-octenol (III) in 30 ml of chloroform took up 1.68 g of O_3 (106.3%). The ozonide was decomposed with water, and the excess peroxide was decomposed by heating with Pt. The solution was made up to 500 ml. Aliquots were taken and found to contain 38.6% formaldehyde (with dimedon) and 25.2% formic acid. After removal of the formaldehyde the first drops of the neutral products distillate gave a precipitate of a 2,4-dinitrophenylhydrazone with m.p. 122-123°, which did not depress the mixed melting point with the 2,4-dinitrophenylhydrazone of acetone. We were unable to identify the other products of the ozonolysis.

For hydrogenation we took 2.0 g of 7-methyl-3-methylene-6-octenol (III), 1.0 g of $Pd/CaCO_3$ and 40 ml of alcohol. The amount of hydrogen absorbed was 321 ml (103.6% of the theoretical for one double bond). After removal of the alcohol by distillation we obtained 1.2 g of citronellol (V). A mixture of 1.2 g of citronellol (V), 1.5 g of $Na_2Cr_2O_7$ and 2 ml of water at 60-70° was treated in drops with 2 ml of 60% H_2SO_4. The mixture was kept at this temperature for one hour, after which it was steam-distilled. The aqueous distillate was extracted with ether, and after distilling off the ether we obtained the lactone, which was converted to the sodium salt of the acid by boiling with an excess of caustic in aqueous alcohol (1 : 1) solution. After evaporation of the alcohol and neutralization of the solution with nitric acid, the sodium salt was converted to the silver salt.

Found %: C 43.23; H 6.73; Ag 38.80. $C_{10}H_{17}O_2Ag$. Calculated %: C 43.34; H 6.18; Ag 38.92.

Another 5.0 g of citronellol (V) was oxidized repeatedly by the Tiemann-Schmidt procedure [10]. We obtained 3.1 g of neutral products (mainly the original alcohol) and 0.7 g of citronellic acid.

Found %: equiv. 170.1. $C_9H_{17}COOH$. Calculated %: equiv. 170.2.

The results given above were obtained when the silver salt was analyzed. The infrared absorption spectra were taken with an IKS-6 spectrophotometer, using a NaCl prism, and running at third speed.

SUMMARY

1. When dimethylvinylcarbinol is reacted with aqueous $KHSO_4$ solution there is observed, together with allylic rearrangement, dehydration and dimerization, also hydration, leading to the formation of α,α-dimethyltrimethylene glycol and geraniol hydrate.

2. The dehydration of geraniol hydrate in the presence of trace amounts of $KHSO_4$ gives a $C_{10}H_{18}O$ alcohol, which is mainly 7-methyl-3-methylene-6-octenol.

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SYNTHESIS OF HYDRAZIDES AND HYDRAZONES OF SOME HETEROCYCLIC AND AROMATIC ACIDS

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In earlier investigations [1] it had been shown that isonicotinic acid hydrazide and its derivatives (hydrazones) show substantial antituberculous activity, both in vitro and in vivo. In this connection it seemed of interest to synthesize, for testing as possible antituberculous agents, the hydrazides, and their derivatives of 4-pyridylacetic acid, β-(4-pyridyl)acrylic acid and β-(4-pyridyl)propionic acid, differing from the isonicotinoylhydrazone in having one or more methylene groups between the pyridine ring and the hydrazide radical.

It also seemed desirable to synthesize the hydrazides and hydrazones of acids belonging to the piperidine and quinuclidine series for the purpose of determining the influence exerted by the indicated rings on the biological activity of this class of compounds and to compare this activity with that shown by similar compounds of the pyridine series.

With this in mind we synthesized the hydrazides of the following acids: isonipecotic, 4-pyridylacetic, 4-piperidylacetic, β-(4-pyridyl)propionic, β-(4-piperidyl)propionic, β-(4-pyridyl)acrylic, 6-methylpicolinic and α-quinuclidinecarboxylic. Due to the fact that p-nitrobenzoic acid is close to isonicotinic acid in its chemical properties, to determine the relationship between structure and activity we also synthesized the hydrazide and some hydrazones of p-nitrobenzoic acid. To synthesize the hydrazides we reacted our earlier obtained [5, 6] ethyl esters of the mentioned acids with hydrazine hydrate in alcohol solution. Subsequent reaction of the hydrazides with various aldehydes (benzaldehyde, 4-acetamidobenzaldehyde, 4-hydroxy-3-methoxybenzaldehyde, 4-hydroxybenzaldehyde, opianic acid) led to obtaining the hydrazones. This last reaction was run in water, aqueous alcohol or alcohol medium. The constants of the obtained compounds, their analysis and the yields are summarized in Tables 1-4.* The in vitro testing of the obtained compounds for antituberculous activity, run in the Chemotherapy Section of our Institute by O.O. Makeeva, revealed that they show considerably less activity than do the corresponding isonicotinic acid derivatives.

EXPERIMENTAL

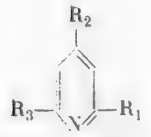
As examples we will describe the synthesis of 6-methylpicolinic acid hydrazide, p-acetamidobenzaldehyde 6-methylpicolinoylhydrazone, benzaldehyde 4-pyridylacetylhydrazone and 4-hydroxy-3-methoxybenzaldehyde α-quinuclidinoylhydrazone.

6-Methylpicolinic acid hydrazide. To a solution of 6.5 g of ethyl 6-methylpicolinate in 10 ml of ethyl alcohol was added 4.2 g of hydrazine hydrate and the mixture heated for three hours at the boil. The alcohol and excess hydrazine hydrate were removed by distillation. The crystalline residue was pressed on a Buchner funnel and washed with anhydrous ether. We obtained 5.35 g (92%) of the compound, m.p. 91-93°.

p-Acetamidobenzaldehyde 6-methylpicolinoylhydrazone. A hot solution of 1.08 g of p-acetamidobenzaldehyde in 22 ml of water was added to a solution of 1 g of 6-methylpicolinic acid hydrazide in 5 ml of hot water. The precipitate obtained on cooling was filtered and washed with hot water. We obtained 1.78 g (91%) of the compound. M.p. 247-249° (from alcohol).

*At the time we completed the present investigation we found that some of the hydrazides prepared by us had already appeared in the literature. For this reason the proper references are included in the tables.

TABLE 1



R_1	R_2	R_3	Yield (in %)	Melting point	Analysis results (in %)					
					C		H		N	
					calc.	found	calc.	found	calc.	found
H	$CH_2CONHNH_2$	H	Quantitative	90—91°[2, 3]	55.63	55.22	5.96	5.94	27.81	27.61
H	$CH_2CH_2CONHNH_2$	H	95	61—62[3]	58.18	59.86	6.66	6.59	25.45	25.42
$CONHNH_2$	H	CH_3	92	91—93	55.63	55.41	5.96	5.91	27.81	27.46
H	$CH_2CONHN=CHC_6H_3$(m-OCH_3)(p-OH)	H	90	208—209	63.15	62.77	5.27	5.56	14.73	14.29
H	$CH_2CONHN=CHC_6H_4$(p-OH)	H	Quantitative	217—218	—	—	—	—	16.22	16.20
H	$CH_2CONHN=CHC_6H_4$(p-$NHCOCH_3$)	H	62**	226—227	—	—	—	—	16.91	17.03
H	$CH_2CONHN=CHC_6H_5$	H	84.5	116—117	—	—	—	—	17.64	17.58
H	$CH_2CH_2CONHN=CHC_6H_3$(m-OCH_3)(p-OH)	H	86.2	212—214	64.21	64.02	5.70	5.94	14.05	13.92
H	$CH_2CH_2CONHN=CHC_6H_4$(p-$NHCOCH_3$)	H	89.0*	198—199	62.20	62.32	6.03	5.65	17.04	16.74
H	$CH_2CH_2CONHN=CHC_6H_4$(p-OH)	H	49.5	199—200	67.18	66.96	5.55	5.57	15.69	15.62
H	$CH=CHCONHN=CHC_6H_3$(m-OCH_3)(p-OH)	H	57*	124—126	60.95	60.69	5.40	5.41	—	—
H	$CH=CHCONHN=CHC_6H_4$(p-$NHCOCH_3$)	H	89*	171—173	62.54	62.88	5.52	5.28	17.15	17.18
H	$CH=CHCONHN=CHC_6H_4$(p-OH)	H	69	169—171	—	—	—	—	15.73	15.67
$CONHN=CHC_6H_5$	H	CH_3	81	142—144	70.29	70.07	5.43	5.38	17.57	17.47
$CONHN=CHC_6H_2$(o-COOH), (m,p-OCH_3)	H	CH_3	75	235	59.47	59.17	4.95	4.99	12.24	12.06
$CONHN=CHC_6H_4$(p-$NHCOCH_3$)	H	CH_3	91	247—249	64.86	65.12	5.40	5.46	18.24	18.42

*Crystallizes with 1 H_2O.

**Crystallizes with 2 H_2O.

TABLE 2

R	Yield (in %)	Melting point	Analysis results (in %)					
			C		H		N	
			calc.	found	calc.	found	calc.	found
$CONHNH_2$	83*	236—238°[2]	—	—	—	—	19.44	19.06
$CH_3CONHNH_2$	88.4*	227—228	36.52	36.67	7.39	7.55	18.26	18.25
$CH_3CH_2CONHNH_2$	96.5	70—72	—	—	—	—	24.56	24.20
$CONHN{=}CHC_6H_3$(m-OCH_3) (p-OH)	87**	216—217	57.16	57.16	6.80	7.15	14.28	14.30
$CONHN{=}CHC_6H_3$(o-COOH) (m, p-OCH_3)	78**	209	54.39	54.41	6.51	6.54	11.89	11.78
$CH_3CONHN{=}CHC_6H_3$(m-OCH_3) (p-OH)	90**	193—194	58.25	58.50	7.74	7.49	13.59	13.32
$CH_3CH_2CONHN{=}CHC_6H_3$(m-OCH_3)(p-OH)	88.3	223—224	62.95	62.84	7.54	7.22	—	—
$CH_3CH_2CONHN{=}CHC_6H_4$(p-$NHCOCH_3$)	80	210—212	64.62	64.43	7.60	7.72	—	—

TABLE 3

R	Yield (in %)	Melting point	Analysis results (in %)					
			C		H		N	
			calc.	found	calc.	found	calc.	found
$CONHNH_2$	92	91—93°	56.80	56.45	8.87	8.87	24.87	24.45
$CONHN{=}CHC_6H_3$(m-OCH_3) (p-OH)	70**	135—138	59.81	60.00	7.16	7.18	13.08	12.85
$CONHN{=}CHC_6H_5$	70	153—155	70.03	70.42	7.19	7.55	—	—
$CONHN{=}CHC_6H_4$(p-$NHCOCH_3$)	75	251—252	64.26	64.34	7.00	7.22	17.85	17.60
$CONHN{=}CHC_6H_4$(p-OH)	62**	139—141	61.85	61.85	7.21	7.08	14.43	14.99

*Isolated as the dihydrochloride

**Crystallizes with 1 H_2O.

Benzaldehyde 4-pyridylacetylhydrazone. A solution of 0.15 g of benzaldehyde in 1 ml of alcohol, heated to 70°, was added to 0.23 g of 4-pyridylacetic acid hydrazide, dissolved in 1 ml of water at 70°. The solution was evaporated to dryness. The oily residue was rubbed with ether, and then with water; the obtained crystals were filtered and washed with water. We obtained 0.3 g (84.5%) of benzaldehyde 4-pyridylacetylhydrazone, m.p. 116-117°.

4-Hydroxy-3-methoxybenzaldehyde α-quinuclidinoylhydrazone. A solution of 1 g of α-quinuclidinecarboxylic acid hydrazide in 5 ml of alcohol was mixed with a solution of 0.9 g of 4-hydroxy-3-methoxybenzaldehyde in 10 ml of alcohol. Then 15 ml of water was added to the solution. The precipitate obtained on cooling in ice was filtered. We obtained 1.3 g (70%) of the compound. M.p. 136-138° (from alcohol).

TABLE 4

R	Yield (in %)	Melting point	Analysis results (in %)					
			C		H		N	
			calc.	found	calc.	found	calc.	found
$CONHNH_2$	84	208—210°[4]	46.40	46.60	3.86	3.88	23.20	23.59
$CONHN{=}CHC_6H_3(m\text{-}OCH_3)(p\text{-}OH)$	80*	226—227	54.05	54.09	4.50	4.54	—	—
$CONHN{=}CHC_6H_3(o\text{-}COOH)(m,p\text{-}OCH_3)$	75	247	—	—	—	—	11.22	11.27
$CONHN{=}CHC_6H_4(p\text{-}OH)$	86	266—268	58.94	58.83	3.85	3.86	14.73	14.84

*Crystallizes with 1 H_2O.

SUMMARY

To study the antituberculous activity we synthesized the hydrazides and some hydrazones of isonipecotic, 4-pyridylacetic, 4-piperidylacetic, β-(4-pyridyl)propionic, β-(4-piperidyl)propionic, β-(4-pyridyl)acrylic, 6-methylpicolinic, α-quinuclidinecarboxylic and p-nitrobenzoic acids.

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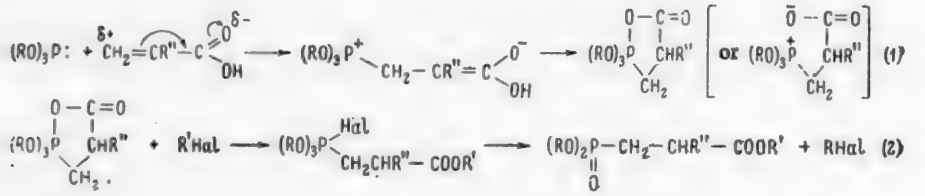
ADDITION OF NEUTRAL ESTERS OF PHOSPHOROUS AND PHOSPHONOUS ACIDS TO CONJUGATED SYSTEMS

VI. JOINT REACTION OF ALKYL HALIDES AND α,β-UNSATURATED ACIDS WITH TRIALKYL PHOSPHITES

V.A. Kukhtin and K.M. Orekhova

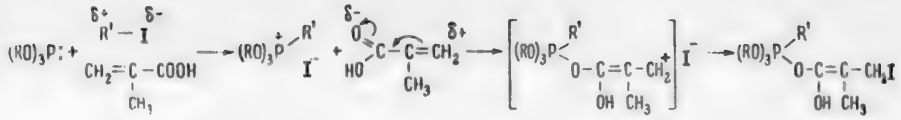
In earlier papers [1, 2] it had been shown that trialkyl phosphites can undergo the Arbuzov rearrangement when reacted with α,β-unsaturated acids and aldehydes. The indicated authors also established that α,β-unsaturated acids and alkyl halides are capable of joint reaction with trialkyl phosphites [3]. As a continuation of these investigations we studied the joint reaction of α,β-unsaturated acids and alkyl bromides or iodides with trialkyl phosphites. The experiments run using alkyl bromides completely confirmed the earlier-proposed scheme. As a result of these experiments we obtained the mixed esters of β-dialkylphosphonocarboxylic acids and the corresponding alkyl halides. The constants of the obtained esters are given in Table 1.

Heating was employed when methacrylic acid and alkyl bromides were jointly reacted with trialkyl phosphites. The joint reaction of acrylic acid and alkyl bromides with trialkyl phosphites proceeds more vigorously than in the case of methacrylic acid. In some cases, when the reaction was run at room temperature (Table 2, Expt. 2), the ethyl ester of β-diethylphosphonoisobutyric acid was isolated. The mixed ester could not be found in the reaction products. From this it appears that the alkyl bromide reacts with the intermediate complex mainly at elevated temperature. We studied the reaction of ethyl bromide with the intermediate product obtained as the result of adding tributyl phosphite to methacrylic acid. Butyl bromide and the ethyl ester of β-dibutylphosphonoisobutyric acid were isolated as reaction result. Consequently, the reaction can be depicted as going in two stages.

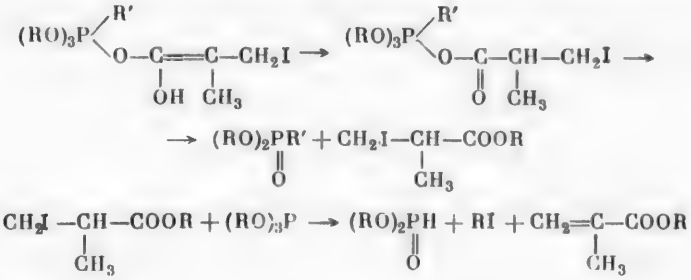


Interesting results were obtained when the joint reaction of methacrylic acid and alkyl iodides with trialkyl phosphites was studied. In this case the yields of esters of β-phosphonoisobutyric acid were small (from 8 to 18%, Table 2).

Consequently, the reaction can also go differently from the above-presented scheme. When the obtained reaction products were fractionally distilled we isolated esters of the general type $R'P(OR)_2$ (O), the formation of which was not observed in studying the reaction with alkyl bromides. In addition, esters of methacrylic acid and dialkylphosphorous acid were obtained as a reaction result (see Table 2). Alkyl iodides are much more active in the Arbuzov rearrangement than are the bromides, and consequently it is possible to theorize that in the first reaction stage they could compete with the methacrylic acid, in which case reaction proceeds by the scheme:



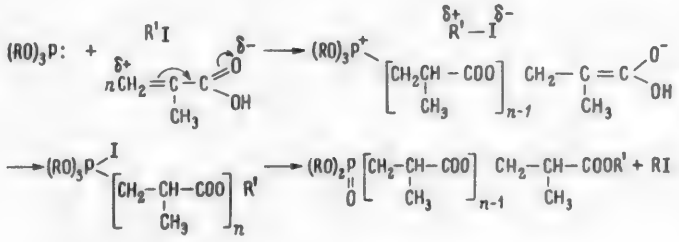
The decomposition of the unstable intermediate compound proceeds in the following manner:



It is also possible for the hydrogen halide to cleave in a different manner; however, we were unable to detect the presence of hydrogen iodide in the reaction products. As a result of reaction by the above-presented scheme the following four products should be isolated: esters of general type $R'P(OR)_2$, dialkylphosphorous acids, $\|$ O

methacrylates and alkyl iodides. It was established that all four products are present in the reactions run by us (Table 2). The joint reaction of acrylic acid and alkyl iodides with trialkyl phosphites goes mainly by the scheme presented above for the alkyl bromides, i.e., with the formation of the corresponding esters of the β-dialkylphosphonopropionic acid. This is apparently due to the fact that acrylic acid, being more reactive, attacks the phosphite molecule before the alkyl iodide does. Then the alkyl iodide reacts with the intermediate complex formed.

In studying the joint reactions of alkyl iodides and methacrylic acid with trialkyl phosphites, the ability of trialkyl phosphites to telomerize at room temperature with methacrylic acid in the presence of alkyl iodides [3] according to the scheme was verified:



The structure of the telomerization product was not investigated. The isolated telomeric products were white, powderlike substances. They did not melt, and when heated they turned dark; they are insoluble in benzene, xylene, toluene, cyclohexane, chloroform, dioxane and carbon tetrachloride, soluble in alkalies and in methyl alcohol (when heated), and slightly soluble in acetone. Their phosphorus content ranged from 2.5 to 6.5%.

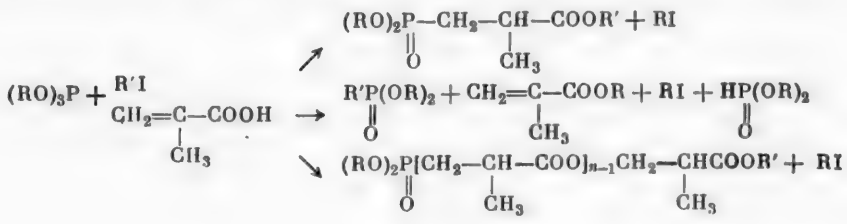


TABLE 1

Expt. No.	Mixed ester of phosphonocarboxylic acid	Boiling point (pressure in mm)	n_D^{20}	d_4^{20}	% P		MR_D		Yield (in %)
					found	calc.	found	calc.	
1	$(C_2H_5O)_2P(=O)-CH_2-CH(CH_3)-COOC_3H_7$-n	139—140° (8)	1.4350	1.068	11.48, 11.68	11.65	65.47	65.10	27.8
2	$(C_2H_5O)_2P(=O)-CH_2-CH(CH_3)-COOC_4H_9$-iso	144—146 (9)	1.4360	1.052	11.09, 10.99	11.07	70.09	70.95	17.8
3	$(C_2H_5O)_2P(=O)-CH_2-CH(CH_3)-COOC_5H_{11}$-iso	146—148 (8)	1.4310	1.001	10.32, 10.20	10.54	78.72	77.93	13.6
4	$(C_2H_5O)_2P(=O)-CH_2-CH_2-COOC_3H_7$-iso	150—151 (8)	1.4335	1.071	11.82, 12.09	12.22	60.85	61.20	79.0
5	$(C_2H_5O)_2P(=O)-CH_2-CH_2-COOC_3H_7$-n	154—156 (12)	1.4330	1.070	12.22, 12.01	12.22	60.85	59.10	52.0
6	$(C_2H_7O)_2P(=O)-CH_2-CH(CH_3)-COOC_4H_9$-iso	164—165 (9)	1.4370	1.007	10.36, 10.10	10.22	78.43	78.28	53.5
7	$(C_4H_9O)_2P(=O)-CH_2-CH(CH_3)-COOC_3H_7$-n	178—180 (8)	1.4410	1.023	9.92, 9.81	9.62	83.94	83.12	42.6
8	$(C_4H_9O)_2P(=O)-CH_2-CH(CH_3)-COOC_4H_9$	180 (10)	1.4420	1.033	10.04, 9.88	10.06	79.36	78.88	8.4
9	$(C_4H_9O)_2P(=O)-CH_2-CH_2-COOC_2H_5$	190—192 (4)	1.4385	1.026	10.01, 10.30	10.54	74.67	75.30	55.0

TABLE 2

Expt. No.	Reactants and reaction temperature	Products isolated	Boiling point (pressure in mm)	n_D^{20}	d_4^{20}	% P found	% P calc.	MR_D found	MR_D calc.	Yield (in %)
1	$(C_2H_5O)_3P$	$CH_2=C(CH_3)-COOC_2H_5$	—	1.4160	—	—	—	—	—	20.0
	$CH_2=C(CH_3)-COOH$	$(C_2H_5O)_2POH$	72—76° (12)	1.4090	—	—	—	—	—	55.8
	C_2H_7Br-n, 95—96°	$(C_2H_5O)_2P(=O)-CH_2-CH(CH_3)-COOC_2H_7$-n	139—140 (8)	1.4350	1.068	11.48, 11.68	11.65	65.47	64.10	27.8
2	$(C_2H_5O)_3P$	C_2H_7Br-n	68—72	1.4320	—	—	—	—	—	88.0
	$CH_2=C(CH_3)-COOH$	$(C_2H_5O)_2POH$	70—73 (10)	1.4080	—	—	—	—	—	19.0
	C_2H_7Br-n, 16°	$(C_2H_5O)_2P(=O)-CH_2-CH(CH_3)-COOC_2H_5$	140—142 (8)	1.4340	1.081	11.90, 12.12	12.30	60.90	60.75	57.5
3	$(C_4H_9O)_3P$	C_4H_9Br-n	101—102	1.4930	—	—	—	—	—	27.0
	$CH_2=C(CH_3)-COOH$	$CH_2=C(CH_3)-COOC_4H_9$	52—52.5 (9)	1.4180	—	—	—	—	—	17.0
	C_2H_7Br-n	$(C_4H_9O)_2POH$	114—116 (8)	1.4220	—	—	—	—	—	36.0
	95—96°	$(C_4H_9O)_2P(=O)-CH_2-CH(CH_3)-COOC_2H_7$-n	178—180 (8)	1.4410	1.023	9.92, 9.81	9.62	83.94	83.12	42.6
4	$(C_2H_7O)_3P$	C_2H_7Br-n	68—72	1.4330	—	—	—	—	—	12.0
	$CH_2=C(CH_3)-COOH$	$(C_2H_7O)_2P(=O)-CH_2-CH(CH_3)-COOC_4H_9$-iso	164.5—165 (9)	1.4370	1.007	10.36, 10.10	10.07	78.43	78.28	53.5
	C_4H_9Br-iso, 95—97°									

(continued)

TABLE 2 (continued)

Expt. No.	Reactants and reaction temperature	Products isolated	Boiling point (pressure in mm)	n_D^{20}	d_4^{20}	% P found	% P calc.	MR_D found	MR_D calc.	Yield (in %)
5	$(C_2H_5O)_3P$ $CH_2=CH-COOH$ C_3H_7Br-iso 85°	$(C_2H_5O)_2P(=O)-CH_2-CH_2-COOC_3H_7$-iso	150—151 (8)	1.4335	1.071	11.82 12.09	12.22	60.85	61.20	79.0
6	$(C_2H_5O)_3P$ $CH_2=CH-COOH$ C_3H_7Br-iso 20°	$(C_2H_5O)_2P(=O)-CH_2-CH_2-COOC_3H_7$-n	154.6 (12)	1.4330	1.070	12.22 12.01	12.22	60.85	59.10	52.0
7	$(C_2H_5O)_3P$ $CH_2=C(CH_3)-COOH$ C_4H_9I-iso 15°	$(C_2H_5O)_2P(=O)[CH_2-CH(CH_3)-COO]_{11}C_4H_9$-iso	—	—	—	2.39 2.59	2.72	—	—	39.2
		C_2H_5I	72—73	1.5030	—	—	—	—	—	10.6
		$CH_2=C(CH_3)-COOC_3H_8$	116—120	—	—	—	—	—	—	—
		$(C_2H_5O)_2POH$	72—74 (12)	1.4060	—	—	—	—	—	19.0
		$(C_2H_5O)_2P(=O)-CH_2-CH(CH_3)-COOC_4H_9$-iso	144—146 (9)	1.4360	1.0520	11.09 10.99	11.19	70.09	70.95	17.8
8	$(C_2H_5O)_3P$ $CH_2=C(CH_3)-COOH$	$(C_2H_5O)_2P(=O)[CH_2-CH(CH_3)-COO]_4C_4H_{11}$ iso	—	—	—	6.03 6.13	5.61	—	—	71.8
		C_2H_5I	73—74	1.5060	—		—	—	—	10.6
		$(C_2H_5O)_2POH$	70—74 (10)	1.4090	—	—	—	—	—	19.0

(continued)

TABLE 2 (continued)

Expt. No.	Reactants and reaction temperature	Products isolated	Boiling point (pressure in mm)	n_D^{20}	d_4^{20}	% P found	% P calc.	MR_D found	MR_D calc.	Yield (in %)
8	C_5H_{11}-iso	iso-$C_5H_{11}P(OC_2H_5)_2$ (O)	120—122 (8)	1.4290	—	—	—	—	—	25.0
	16°	$(C_2H_5O)_2PCH_2-CH(CH_3)-COOC_5H_{11}$-iso (O)	146—148 (8)	1.4310	1.001	10.32, 10.20	10.54	78.72	77.93	13.6
9	$(n\text{-}C_4H_9O)_3P$	C_4H_9J-n	130—132	1.4980	—	—	—	—	—	20.0
	$CH_2=C(CH_3)-COOH$	$(C_4H_9O)_2P[CH_2-CH(CH_3)-COO]_4C_2H_5$ (O)	—	—	—	5.83, 5.25	5.55	—	—	6.8
	C_2H_5I	$(C_4H_9O)_2PC_2H_5$ (O)	135—140 (11)	1.4240	—	—	—	—	—	10.0
	16°	$(C_4H_9O)_2PCH_2-CH(CH_3)-COOC_2H_5$ (O)	180 (10)	1.4420	1.033	10.04, 9.88	10.06	79.32	78.88	8.4
10	$(n\text{-}C_4H_9O)_3P$	C_4H_9I-n	131—133	1.4905	—	—	—	—	—	20.0
	$CH_2=CH-COOH$	$(C_4H_9O)_2POH$	106—108 (5)	1.4225	—	—	—	—	—	24.0
	C_2H_5I	$(C_4H_9O)_2PCH_2-CH_2-COOC_2H_5$ (O)	190—192 (4)	1.4385	1.026	10.01, 10.30	10.54	74.67	75.30	55.0
	20°									
11	O—C=O / $(C_4H_9O)_2P$ CHCH$_3$ / CH_2	C_4H_9Br-n	28—29 (30)	1.4970	—	—	—	—	—	30.0
	C_2H_5Br	$(C_4H_9O)_2PCH_2-CH(CH_3)-COOC_2H_5$ (O)	180—181 (9)	1.4420	1.034	—	—	—	—	58.5
	80°									

The experimental results obtained by us permit making the conclusion that, depending on the experimental conditions and chemical reactivity of the reactants, the joint reaction of methacrylic acid and alkyl iodides with trialkyl phosphites can go in three directions.

EXPERIMENTAL

Reaction of triethyl phosphite with methacrylic acid and propyl bromide. To 15 g of triethyl phosphite and 11.1 g of propyl bromide was added 7.78 g of methacrylic acid. A rise of 2° in the temperature was observed. When heat evolution had ceased, the reaction mass was heated on the water bath (the mixture boiled at 95-96°) for six hours. Three fractional distillations gave 8 g of the propyl ester of β-diethylphosphonoisobutyric acid (Table 1, Expt. 1). The other experiments involving the reaction of alkyl bromides and methacrylic acid with trialkyl phosphites were run in a similar manner.

Reaction of ethyl bromide with the reaction product of methacrylic acid and tributyl phosphite. Methacrylic acid (9.6 g) was added in drops to 25 g of tributyl phosphite. The mixture was stirred thoroughly. After three days the reaction was considered completed (test for trivalent phosphorus with CuHal showed the absence of tributyl phosphite). Then 12.1 g of ethyl bromide was added to the reaction mass. The reaction mixture was heated on the water bath for three hours. After three fractional distillations we obtained 20 g of the ethyl ester of β-dibutylphosphonoisobutyric acid (Table 2, Expt. 11).

Reaction of triethyl phosphite with methacrylic acid and isoamyl iodide. A mixture of 20 g of triethyl phosphite, 23.8 g of isoamyl iodide and 10.3 g of methacrylic acid was allowed to stand at room temperature. After two days a white precipitate appeared in the flask, the amount of which increased with time. When reaction was complete the precipitate was filtered. The total amount of precipitate was 11.6 g, which after washing was a white powder, which did not melt, but gradually charred at 240-250°. The precipitate is insoluble in carbon tetrachloride, ether, chloroform, benzene and dioxane, slightly soluble in acetone, and readily soluble in methyl alcohol (when heated) (Table 2, Expt. 8).

Found %: C 54.60; H 7.78. P 6.03, 6.13. M 411 (ebullioscopically with methyl alcohol). $C_{25}H_{45}O_{11}P$. Calculated %: C 54.35; H 8.15; P 5.61. M 552.

The analysis data correspond to the formula

$$(C_2H_5O)_2P[CH_2-\underset{\underset{O}{\|}}{CH}-\underset{\underset{CH_3}{|}}{C}OO]_3CH_2-\underset{\underset{CH_3}{|}}{CH}-COOC_5H_{11}\text{-iso}$$

Fractional distillation of the liquid portion of the reaction products gave 2 g of ethyl iodide, 3 g of diethylphosphorous acid, 1 g of the diethyl ester of isoamylphosphonic acid and 5 g of the isoamyl ester of β-diethylphosphonoisobutyric acid. The other experiments involving the joint reaction of alkyl iodides and methacrylic acid with trialkyl phosphites were run in a similar manner.

Reaction of tributyl phosphite and acrylic acid with ethyl iodide. Acrylic acid (5.76 g) was added in drops to 20 g of tributyl phosphite and 12.5 g of ethyl iodide. The reaction went with the evolution of heat and the temperature rose to 62°. Further reaction was run at room temperature. After two days the reaction was considered complete and the material was fractionally distilled. We obtained 13 g of the ethyl ester of β-dibutylphosphonopropionic acid (Table 2, Expt. 10).

SUMMARY

1. The joint reaction of α,β-unsaturated acids and alkyl halides with trialkyl phosphites was investigated.

2. It was established that, depending on the reaction conditions and chemical reactivity of the reactants, the reaction can go in several directions.

3. Some new mixed esters of β-phosphonocarboxylic acids were obtained.

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*Original Russian pagination. See C.B. translation.

[2] Gil'm Kamai and V.A. Kukhtin, J. Gen. Chem. 27, 2372 (1957).*

[3] V.A. Kukhtin and Gil'm Kamai, J. Gen. Chem. 28, 1196 (1958).*

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1-AMINOMETHYL-4-PHTHALAZONE

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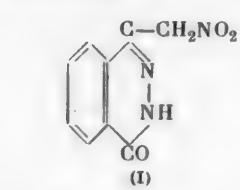
We recently obtained [1] 1-nitromethyl-4-phthalazone (I) by reacting hydrazine hydrate with 2-nitro-1,3-indandione. Since phthalazone derivatives are frequently physiologically active compounds (antituberculous agents, antihypertensives, etc.), it seemed of interest to prepare some derivatives of the nitromethylphthalazone. To obtain a water-soluble compound we reduced the nitromethylphthalazone. Various reducing agents were examined, but the best results were obtained using hydriodic acid and red phosphorus. With these reducing agents, the nitro group was smoothly reduced to the amino group, and the obtained 1-aminomethyl-4-phthalazone (II) was isolated as the hydriodide. This salt is readily soluble in water. As a compound with a primary amino group it gives a positive test with bindone [2], yields the difficultly soluble nitroindandionate [3] and reacts with phthalic anhydride [4] to give 1-phthalimidomethyl-4-phthalazone (III). The monobenzoyl derivative (IV) is formed when 1-aminomethyl-4-phthalazone is reacted with benzoyl chloride in alkaline medium, and the diacetyl derivative when (II) is reacted with acetic anhydride.

Of the three forms possible for this compound (V-VII) it appears that (VI) is the most probable. That the amino group of 1-aminomethyl-4-phthalazone acetylates is obvious from the fact that 1-phthalimidomethyl-4-phthalazone also gives an acetyl derivative (VIII), obtained as colorless crystals.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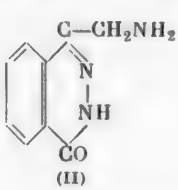
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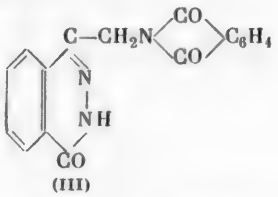
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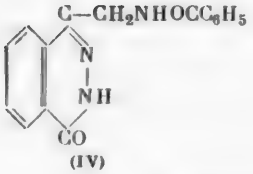
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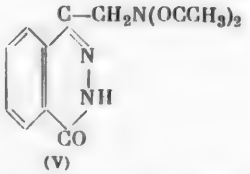
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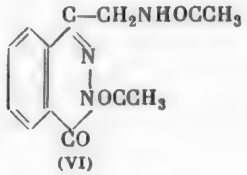
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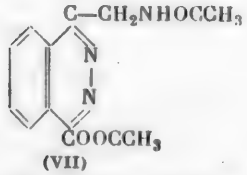
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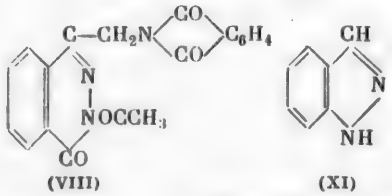
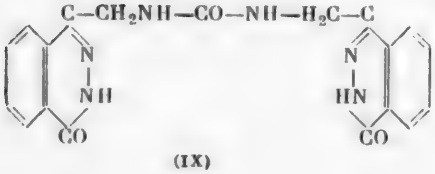

(VIII)

(XI)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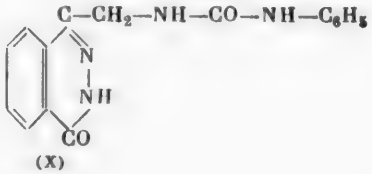
(X)

Treatment of an aqueous solution of the 1-aminomethyl-4-phthalazone hydriodide with hydrochloric acid gives a precipitate of the much less soluble hydrochloride.

We were unable to obtain the free base from the salts in a pure form. If a solution of the aminomethylphthalazone salt was treated with concentrated ammonia, then the liquid turned a reddish violet and a crystalline precipitate deposited rapidly. The filtered precipitate was nearly colorless, while the filtrate was reddish in color. The precipitate had a pyridinelike odor, and quickly deliquesced and decomposed with the evolution of ammonia. We were unable to recrystallize the free base.

When the hydrochloride of 1-aminomethyl-4-phthalazone was heated with urea in water solution, it proved that a hydrogen atom on each of the amino groups of urea was replaced by the methylphthalazone radical with the formation of N,N'-bis(4-phthalazonylmethyl)urea (IX). Only one molecule of the 1-aminomethyl-4-phthalazone reacts with phenylurea to give (X), while with N,N'-diphenylurea the reaction completely fails to go.

A white substance is formed when the nitromethylphthalazone is heated with zinc dust in a hydrogen stream, which, judging from the melting point, nitrogen content and other properties, is indazole (XI). It is entirely possible for the latter to be formed under the reaction conditions.

EXPERIMENTAL

1-Aminomethyl-4-phthalazone (II). A mixture of 1 g of 1-nitromethyl-4-phthalazone, 20 ml of hydriodic acid (b.p. 124°) and 1 g of red phosphorus was heated in a small flask under reflux for one hour. The hot solution was suction-filtered through a glass filter. The filtrate on cooling deposited lustrous crystals of the 1-aminomethyl-4-phthalazone hydriodide. The crystals were filtered, dissolved in alcohol, and precipitated with ether. Yield 1 g, m.p. 266-267° (decomp.). The compound is insoluble in other common solvents, and is readily soluble in water; it dissolves in ammonia and alkalies with a red color. The test with bindone is positive.

Found %: N 13.74; I 41.61. $C_9H_9ON_3 \cdot HI$. Calculated %: N 13.87; I 41.84.

Nitroindandionate. A saturated water solution of 1-aminomethyl-4-phthalazone hydriodide was treated with a saturated water solution of 2-nitro-1,3-indandione. A yellow crystalline precipitate of the 1-aminomethyl-4-phthalazone nitroindandionate soon deposited. The compound is insoluble in water and in alcohol. M.p. 233-235° (decomp.). For analysis the salt was washed several times with water.

Found %: N 14.83. $C_{18}H_{14}O_5N_4$. Calculated %: N 15.29.

Hydrochloride. A water solution of 1-aminomethyl-4-phthalazone hydriodide was treated with concentrated hydrochloric acid. The hydrochloride deposited as white needle crystals. After recrystallization from anhydrous alcohol, m.p. 308°.

Found %: N 19.80; Cl 17.08. $C_9H_9ON_3 \cdot HCl$. Calculated %: N 19.86; Cl 16.76.

1-Benzamidomethyl-4-phthalazone. A solution of 0.1 g of 1-aminomethyl-4-phthalazone hydriodide in 10 ml of 2% potassium hydroxide was treated with two drops of benzoyl chloride and the mixture shaken until the odor of the benzoyl chloride had disappeared. Within a few minutes the 1-benzamidomethyl-4-phthalazone deposited as fine white crystals. After recrystallization from anhydrous alcohol, m.p. 257-258°. The compound is insoluble in alkalies. When heated with alkali the compound gradually decomposes with the evolution of ammonia.

Found %: N 14.85. $C_{16}H_{13}O_2N_3$. Calculated %: N 15.05.

1-Phthalimidomethyl-4-phthalazone (III). A mixture of 1 g of 1-aminomethyl-4-phthalazone hydriodide, 2.5 g of phthalic anhydride, 0.5 g of anhydrous sodium acetate and 25 ml of glacial acetic acid was refluxed for 1.5 hours. The precipitate gradually went into solution, and then the 1-phthalimidomethyl-4-phthalazone began to deposit as a finely crystalline precipitate. The flask contents were diluted with 250 ml of water, and the mixture heated to the boil and then allowed to stand until the next day. The precipitate was separated and recrystallized from glacial acetic acid using activated carbon. M.p. 353°.

Found %: N 13.62. $C_{17}H_{11}O_3N_3$. Calculated %: N 13.77.

1-Acetamidomethyl-3-acetyl-4-phthalazone (VI). A mixture of 1 g of 1-aminomethyl-4-phthalazone hydrochloride, 2.5 g of anhydrous sodium acetate and 25 ml of acetic anhydride was refluxed for ten hours, the

acetic anhydride distilled off, and the residue recrystallized from dilute methanol (1:1). M.p. 226-227°. The compound is insoluble in water, and readily soluble in alcohol; cautious dilution of the alcohol solution with water until turbidity appeared led to the deposition of long glistening needles.

Found %: N 16.60. $C_{19}H_{12}O_3N_3$. Calculated %: N 16.22.

1-Phthalimidomethyl-3-acetyl-4-phthalazone (VIII). A mixture of 1-phthalimidomethyl-4-phthalazone and acetic anhydride was refluxed for ten hours. A white crystalline precipitate was obtained on cooling. The precipitate was separated and washed with ether. M.p. 207°.

Found %: N 12.38. $C_{19}H_{13}O_4N_3$. Calculated %: N 12.54.

The compound is soluble in glacial acetic acid and alcohol, and when its solutions are boiled, a precipitate of 1-phthalimidomethyl-4-phthalazone is obtained. M.p. 353°.

N,N'-Bis(4-phthalazonylmethyl)urea (IX). A mixture of 1 g of 1-aminomethyl-4-phthalazone hydrochloride, 0.6 g of urea (mole ratio 1:2) and 100 ml of water was refluxed for four hours. A precipitate began to deposit within an hour. The compound is insoluble in cold water, alcohol and glacial acetic acid, and is soluble in alkalies. Ammonia is evolved when the compound is heated with concentrated caustic solution. After recrystallization from hot water, m.p. 320-325° with partial sublimation.

Found %: N 23.12, 22.63. $C_{19}H_{16}O_3N_6$. Calculated %: N 22.34.

Somewhat high results were frequently obtained when the compound was analyzed for nitrogen. It is obvious that here the product obtained by the condensation of the reactants in a 1:2 ratio is contaminated with the product obtained by the condensation of the reactants in a 1:1 ratio. However, we were unable to isolate the indicated compound in pure form by fractional crystallization.

N-Phenyl-N'-(4-phthalazonylmethyl)urea (X). A mixture of 1 g of the aminomethylphthalazone hydrochloride, 0.8 g of phenylurea and 60 ml of water was refluxed for two hours. We obtained 2 g of N-phenyl-N'-(4-phthalazonylmethyl)urea from the reaction. M.p. 300-301°. The compound is very difficultly soluble in alcohol, xylene, dioxane and glacial acetic acid.

Found %: N 19.15. $C_{16}H_{14}O_2N_4$. Calculated %: N 19.05.

Indazole (XI). A mixture of 1 g of the nitromethylphthalazone and 30 g of zinc dust was heated in a glass tube in a stream of hydrogen. A white deposit collected on the cold sides of the tube. The flask contents after cooling were shaken with ether, and the filtrate was evaporated. The white residue was recrystallized from water. Fine crystals with a peculiar, sweet odor. Yield 0.05 g, m.p. 140-143°.

Found %: N 23.21. $C_7H_6N_2$. Calculated %: N 23.72.

SUMMARY

The reduction of 1-nitromethyl-4-phthalazone gave 1-aminomethyl-4-phthalazone. The properties of the latter were studied, and some of its derivatives were prepared.

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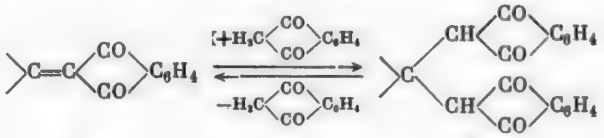
COMPOUNDS WITH TWO GEMINATE INDANDIONE GROUPS IN THE MOLECULE

II. CONDENSATION OF 5,6-DINITROACENAPHTHENEQUINONE WITH 1,3-INDANDIONE

L.S. Geita and G.Ia. Vanag

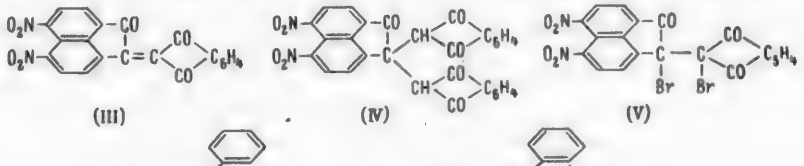
In previous papers [1-6] we had shown that many carbonyl compounds condense readily with 1,3-indandione; here, depending on the ratios of the two components, and also the reaction conditions, it is frequently possible to isolate both indandionylene derivatives of type (I) and diindandionyl derivatives of type (II). The first type usually easily add another molecule of the indandione and migrate to the second type; the latter, in turn, can cleave a molecule of the indandione and revert back to the first type.



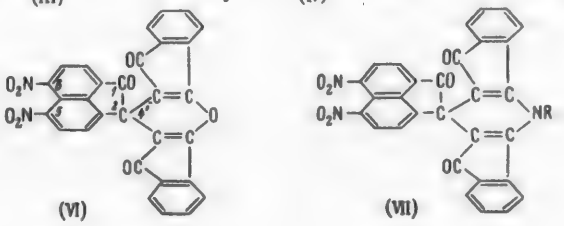
(I) (II)

Such mutual interconversions were accomplished with the condensation products of the indandione with benzaldehyde, the nitrobenzaldehydes and acenaphthenequinone, whereas with phenanthrenequinone and nitrophenanthrenequinone only compounds of the (II) type could be obtained. In the present paper we studied the condensation of 5,6-dinitroacenaphthenequinone with 1,3-indandione.

When 5,6-dinitroacenaphthenequinone is condensed with 1,3-indandione in an equimolar ratio in glacial acetic acid the reaction goes in two directions, and both red crystals of 5,6-dinitro-2-indandionylene-1-acenaphthenone (III) and colorless crystals of 5,6-dinitro-2,2-diindandionyl-1-acenaphthenone (IV) are formed. To obtain pure (III) it is advisable to take a large amount of solvent, since colorless (IV) is somewhat more soluble in glacial acetic acid. In general, both compounds have nearly the same solubility, which makes their complete separation quite difficult. This is accomplished by repeated boiling with either chloroform or glacial acetic acid, or by careful treatment with warm pyridine. The use of alkali to separate the two compounds is not practical here, since (III) is also soluble in alkali; acidification of the solution gives an amorphous precipitate, which dissolves in sodium bicarbonate. From the literature it is known [7] that the indandione ring, devoid of an active hydrogen in the 2 position, is frequently easily cleaved by alkali with the formation of a carboxylic acid.



(III) (IV) (V)



(VI) (VII)

5,6-Dinitro-2-indandionylene-1-acenaphthenone readily adds another molecule of the indandione, and here 5,6-dinitro-2,2-diindandionyl-1-acenaphthenone (IV) is formed. 5,6-Dinitro-2-indandionylene-1-acenaphthenone also adds a molecule of bromine, but the obtained dibromide (V) is unstable and again easily cleaves bromine. If dibromide (V) is treated with alcohol, then an atom of bromine still remains in the molecule. The nature of this compound has still not been determined. We were unable to add hydrobromic acid to the double bond of (III).

5,6-Dinitro-2,2-diindandionyl-1-acenaphthenone (IV), obtained by adding the indandione to 5,6-dinitro-2-indandionylene-1-acenaphthenone (III), is more conveniently obtained by the direct condensation of 5,6-dinitroacenaphthenequinone with the indandione in a 1:2 ratio in either alcohol or glacial acetic acid solution. The properties of (IV) in general resemble those of the other geminal diindandionyl derivatives studied earlier. 5,6-Dinitro-2,2-diindandionyl-1-acenaphthenone dissolves in alkalies, forming salts, but these enolic salts are difficult to isolate in the pure state. When treated with acetic anhydride, (IV) is easily cyclized to the corresponding spiro-pyran (VI). The latter reacts with difficulty with ammonia and amines, being converted to the corresponding dihydropyridines (VII). In the case of ammonia, such conversion could be effected only by reaction with liquid ammonia in a sealed tube.

EXPERIMENTAL

5,6-Dinitro-2-indandionylene-1-acenaphthenone (III). To a suspension of 1 g of 5,6-dinitroacenaphthenequinone in 50 ml of glacial acetic acid, heated to the boil, was added 1.04 g of the indandione and five drops of concentrated hydrochloric acid, and the boiling was continued. Within five minutes the starting substance had dissolved and fine red crystals, contaminated with colorless crystals, began to separate. After refluxing for 15 minutes the hot solution was filtered, followed by washing with hot glacial acetic acid and then alcohol. The crude 5,6-dinitro-2-indandionylene-1-acenaphthenone remaining on the filter weighed 0.95 g (64.6%). It was treated with a small amount of warm pyridine to remove the small amount of colorless product present. The residue was washed with alcohol and then boiled with glacial acetic acid. The pure 5,6-dinitro-2-indandionylene-1-acenaphthenone had m.p. 300-302°. The compound is soluble in pyridine and dioxane, and slightly soluble in acetone, benzene, glacial acetic acid, chloroform and alcohol; it dissolves in concentrated sulfuric acid with a bright-red color, and in alkali with a brown color.

Found %: N 6.88. $C_{21}H_8O_7N_2$. Calculated %: N 7.00.

After filtering the red crystals, the hot glacial acetic acid filtrate deposited colorless crystals of 5,6-dinitro-2,2-diindandionyl-1-acenaphthenone (IV), contaminated with a small amount of red crystals of (III).

If the above condensation is run on the water bath, then the main product is the colorless dinitrodiindandionylacenaphthenone. If the condensation is run in either somewhat dilute acetic acid solution or in alcohol, then only the colorless product is formed (see further).

5,6-Dinitro-2-indandionylene-1-acenaphthenone dibromide (V). 5,6-Dinitro-2-indandionylene-1-acenaphthenone (0.5 g) was treated with 10 ml of a glacial acetic acid solution of bromine (1:20) and the mixture boiled gently until the precipitate dissolved, which required about ten minutes. Dilution of the filtrate with water gave a white precipitate of the 5,6-dinitro-2-indandionylene-1-acenaphthenone dibromide (0.5 g). The compound melts with decomposition between 150 and 170°. The dibromide is unstable and decomposed when its recrystallization from alcohol, acetone or chloroform was attempted. It also decomposes on standing: it turns yellow and develops a bromine odor. It dissolves in concentrated sulfuric acid with a bright-red color, and in alkali with a reddish-brown color.

Found %: Br 28.88; N 4.87. $C_{21}H_8O_7N_2Br_2$. Calculated %: Br 28.57; N 5.00.

The colorless dibromide was dissolved in acetone. The orange-colored filtrate deposited fine red crystals that had m.p. 300°. Their mixture with 5,6-dinitro-2-indandionylene-1-acenaphthenone did not depress the melting point. The acetone had a strong odor of bromoacetone.

5,6-Dinitro-2,2-diindandionyl-1-acenaphthenone (IV). 1) A mixture of 2 g of 5,6-dinitroacenaphthenequinone, 50 ml of alcohol and 2.08 g of the indandione was refluxed for one hour. The solution turned dark, and fine greenish crystals began to separate from it. The crystals after cooling were filtered and washed with alcohol. The yield of 5,6-dinitro-2,2-diindandionyl-1-acenaphthenone was 3.15 g (78.7%). Recrystallization from a

mixture of chloroform and alcohol gave the compound as colorless crystals with m.p. 218-220°. The compound is soluble in pyridine, chloroform and dioxane, and slightly soluble in acetone and benzene. It slowly dissolves in concentrated sulfuric acid with a red color, and in alkali with a reddish-brown color. For analysis the compound was recrystallized again from glacial acetic acid.

Found %: N 4.91, 5.24. $C_{30}H_{14}O_9N_2$. Calculated %: N 5.13.

2) A mixture of 5,6-dinitro-2-indandionylene-1-acenaphthenone, 20 ml of glacial acetic acid, 0.25 g of the indandione and several drops of concentrated hydrochloric acid was refluxed for two hours. The red crystals gradually decolorized. After washing with alcohol the colorless crystals had m.p. 219-220°. The melting point was not depressed when the crystals were mixed with the compound obtained in the preceding experiment. The same product was obtained when the condensation was run in alcohol solution.

Cleavage with concentrated sulfuric acid. One gram of 5,6-dinitro-2,2-diindandionyl-1-acenaphthenone was dissolved in 10 ml of concentrated sulfuric acid. The red solution was suction-filtered through a glass filter and then poured into approximately 300 ml of water. A dark-yellow amorphous precipitate was obtained. Recrystallization from acetone gave the compound as fine red crystals. M.p. 301°. The mixed melting point with pure 5,6-dinitro-2-indandionylene-1-acenaphthenone was not depressed.

Ammonium salt. A mixture of 1 g of 5,6-dinitro-2,2-diindandionyl-1-acenaphthenone and 25 ml of alcohol was treated with 1 ml of concentrated ammonia. The substance went into solution, and then dark-brown lustrous crystals (0.40 g) deposited from the solution. The compound was washed with alcohol and ether. M.p. 165-170°. The compound is readily soluble in alcohol, and slightly soluble in water; it decomposes when its water solutions are boiled.

Found %: N 7.11. $C_{30}H_{14}O_9N_2 \cdot NH_3$. Calculated %: N 7.46.

Piperidine salt. One gram of 5,6-dinitro-2,2-diindandionyl-1-acenaphthenone was covered with 10 ml of a 10% solution of piperidine in alcohol. The dipiperidine salt deposited from the solution as dark-brown needle crystals. M.p. 183-186°. The salt is soluble in water and in alcohol. For analysis the salt was recrystallized from alcohol.

Found %: N 7.52. $C_{30}H_{14}O_9N_2 \cdot 2C_5H_{11}N$. Calculated %: N 7.82.

5,6-Dinitro-1-acenaphthenone[2:4']spiro-2',3'(CO),6',5'(CO)-dibenzoylenepyran (VI). Two grams of 5,6-dinitro-2,2-diindandionyl-1-acenaphthenone was dissolved in 40 ml of hot acetic anhydride, 1 ml of concentrated sulfuric acid was added, and the mixture was refluxed for 15 minutes. Yellow crystals deposited. The mixture was heated another 30 minutes on the water bath. We obtained 1.3 g of 5,6-dinitro-1-acenaphthenone[2:4']spiro-2',3'(CO),6',5'(CO)-dibenzoylenepyran with m.p. 467°. The compound is soluble in nitrobenzene and pyridine, and insoluble in alkalies; it is slightly soluble in concentrated sulfuric acid with the formation of a reddish-brown color.

Found %: N 5.18. $C_{30}H_{12}O_8N_2$. Calculated %: N 5.30.

5,6-Dinitro-1-acenaphthenone[2:4']spiro-2',3'(CO),6',5'(CO)-dibenzoylene-1',4'-dihydropyridine (VII, R = H). A mixture of 0.2 g of the 5,6-dinitro-1-acenaphthenonespirodibenzoylenepyran (VI) and 5 ml of liquid ammonia was allowed to stand in a sealed ampoule for a day. The compound dissolved in the ammonia, and the liquid turned dark. The ampoule was opened, the ammonia allowed to evaporate, and the residue was recrystallized from dioxane. The dark-red crystals of 5,6-dinitro-1-acenaphthenone[2:4']spiro-2',3'(CO),6',5'(CO)-dibenzoylene-1',4'-dihydropyridine melted at 265°. The substance is soluble in nitrobenzene, dioxane, acetone, glacial acetic acid and chloroform, and is slightly soluble in alcohol.

Found %: N 8.09. $C_{30}H_{13}O_7N_3$. Calculated %: N 7.97.

SUMMARY

Depending on the conditions, the condensation of 5,6-dinitroacenaphthenequinone with 1,3-indandione gave two products: 5,6-dinitro-2-indandionylene-1-acenaphthenone and 5,6-dinitro-2,2-diindandionyl-1-acenaphthenone. The latter is easily cyclized to the corresponding spiro-pyran, and the pyran when treated with ammonia is converted to the corresponding spiro-dihydropyridine.

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β,β-DIHALOPROPIONALDEHYDES

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β,β-Dihalopropionaldehydes CHX_2CH_2CHO (I, X = Cl or Br) have not been obtained in the free state up to now. Only polymeric products were isolated by Kharasch when he attempted to hydrolyze 1,1-dihalo-3-bromo-3-acetoxypropanes $CHX_2CH_2CHBr(OCOCH_3)$ (II, X = Cl) with either acidic or alkaline agents [1].

We were also unable to obtain the aldehydes (I) by the acid hydrolysis of the corresponding acetals $CHX_2CH_2CH(OR)_2$ (III, R = alkyl) [2]; under mild conditions the acetals were recovered unchanged, while under more drastic conditions the cleavage of hydrogen halide occurred with subsequent polymerization of the formed β-haloacroleins. Reaction of (II) (X = Cl or Br) with sodium bisulfite in the presence of excess sulfur dioxide gave us the bisulfite derivatives of aldehydes (I), but their treatment with either acids or bases also failed to yield the free aldehydes (I).

As we had reported earlier [2], acetals (III) are easily converted to the corresponding 1,1,3-trihalo-3-alkoxypropanes $CHX_2CH_2CHX'(OR)$ (IV) when reacted with either phosphorus pentachloride or thionyl chloride. It was established that the shaking of these reactive compounds (IV) with water at room temperature yields homogeneous water solutions of aldehydes (I), from which the latter can be extracted with methylene chloride and then vacuum-distilled in a stream of nitrogen. Later aldehydes (I) were also obtained in a similar manner from compounds (II), but in this case the reaction went much slower and with poorer yields of the aldehyde. Both of the aldehydes (I) obtained by us are liquids with a sharp specific odor, and they both decompose rapidly, even at room temperature, with the evolution of hydrogen halide and the formation of hard polymers; hydroquinone inhibits the decomposition. β,β-Dibromopropionaldehyde is much less stable than the chloro analog, for which reason we were unable to obtain satisfactory analysis results for it.

The (I) compounds give the characteristic reactions for an aldehyde group and form the corresponding crystalline derivatives; the latter easily cleave hydrogen halide, for which reason they are unstable when stored, and melt with decomposition; they can be purified by recrystallization only if acid is absent; if such is not the case, for example, when old samples are recrystallized, the substance suffers complete conversion to the corresponding β-haloacrolein derivative.

The oxidation of (I) (X = Cl) with concentrated nitric acid gave β,β-dichloropropionic acid.

EXPERIMENTAL

Bisulfite derivative of β,β-dichloropropionaldehyde. A mixture of 7.5 g of 1,1-dichloro-3-bromo-3-acetoxypropane [1], 9.1 g of sodium metabisulfite and 25 ml of water was stirred at 80° with constant passage of sulfur dioxide until a homogeneous solution was obtained. The crystals obtained on cooling were filtered, and washed with water, alcohol and then ether. Yield 4.9 g (73%).

Found %: Na 9.80, 9.78. $C_3H_5O_4SCl_2Na$. Calculated %: Na 9.96.

Bisulfite derivative of β,β-dibromopropionaldehyde. The compound was obtained in the same manner as above. Yield 80%. The compound is much less soluble in water than the corresponding dichloro derivative.

Found %: Na 7.37, 7.39. $C_3H_5O_4SBr_2Na$. Calculated %: Na 7.19.

We were unable to obtain the corresponding β,β-dihalopropionaldehydes when the bisulfite derivatives were treated with either sodium bicarbonate solution or 1% hydrochloric acid at 35-40°, followed by extraction with methylene chloride.

β,β-Dichloropropionaldehyde

An emulsion of 10 g of 1,1,3-trichloro-3-methoxypropane [2] in 125 ml of water was shaken for three hours at room temperature, after which the water solution was separated, the residue treated with 25 ml of water, and the shaking continued for another hour, at the end of which time the amount of residue did not exceed 1.0-1.5 g. The combined water solutions were saturated with sodium chloride and then repeatedly extracted with methylene chloride. The extracts were dried over magnesium sulfate. The solvent was removed in vacuo at room temperature, and the residue was distilled in a stream of nitrogen. We obtained 5.0 g (70%) of colorless liquid with a sharp specific odor.

B.p. 43-44° (10 mm), n_D^{20} 1.4660, d_4^{20} 1.3579, MR_D 25.87; calc. 25.79.

Found %: C 28.53, 28.35; H 3.56, 3.49; Cl 54.76, 55.02. $C_3H_4OCl_2$. Calculated %: C 28.34; H 3.17; Cl 55.91.

The aldehyde was also obtained in a similar manner from 1,1-dichloro-3-bromo-3-acetoxypropane (time of hydrolysis six hours, yield 35%).

β,β-Dichloropropionaldehyde is soluble in the common organic solvents, and is insoluble in water.* On standing for one to two hours it decomposes with the evolution of hydrogen chloride and the formation of hard polymeric products; the decomposition is greatly inhibited if the compound is kept in the cold with trace amounts of hydroquinone.

The p-nitrophenylhydrazone was obtained by mixing a water solution of 0.2 g of p-nitrophenylhydrazine hydrochloride with an alcohol solution of 0.2 g of the aldehyde; for purification the reaction product was dissolved in alcohol and then precipitated with water, m.p. 101° (decomp.); soluble in alcohol and ether. The compound decomposes rapidly with the evolution of hydrogen chloride.

Found %: N 16.17, 15.81; Cl 26.80, 26.62. $C_9H_9O_2N_3Cl_2$. Calculated %: N 16.03; Cl 27.09.

The dimedone derivative was obtained by mixing a solution of 0.5 g of dimedone in 50% alcohol with an alcohol solution of 0.2 g of the aldehyde; after two days we obtained 0.4 g of white crystals, m.p. 127.5-128°.

Found %: Cl 17.99, 17.98. $C_{19}H_{26}O_4Cl_2$. Calculated %: Cl 18.25.

The bisulfite derivative was obtained by shaking an alcohol solution of the aldehyde with a water solution of sodium metabisulfite; the properties and analysis results correspond to those given above.

Semicarbazone. A water solution of 1.1 g of semicarbazide hydrochloride and 1.4 g of sodium acetate was gradually added to a solution of 1.2 g of the aldehyde in alcohol; the obtained precipitate was filtered, washed with alcohol, then with water, and immediately recrystallized from aqueous alcohol. M.p. 72-74° (decomp.).

Found %: N 22.53, 22.69; Cl 38.55, 38.74. $C_4H_7ON_3Cl_2$. Calculated %: N 22.82; Cl 38.58.

A sample of the semicarbazone, recrystallized twice from aqueous alcohol, when exposed to the air for several hours began to evolve hydrogen chloride, and here we obtained a compound with m.p. 133-134°, which from the analysis results is the semicarbazone of β-chloroacrolein.

Found %: N 28.60, 28.71; Cl 23.65, 24.46. $C_4H_6ON_3Cl$. Calculated %: N 28.34; Cl 24.02.

β,β-Dibromopropionaldehyde

Obtained in the same manner as β,β-dichloropropionaldehyde (see above) from 13.3 g of 1,1-dibromo-3-chloro-3-methoxypropane [2]. After fractional distillation in vacuo in a stream of nitrogen we obtained 6.5 g (60%) of the compound.

B.p. 49.5-50° (2.5 mm), n_D^{20} 1.5385, d_4^{20} 2.0769, MR_D 32.40; calc. 31.60.

The aldehyde has a sharp specific odor, is extremely unstable, and decomposes rapidly with the evolution of hydrogen bromide and the formation of hard polymeric products.

*Aldehydes (I) after extraction, drying and distillation, are insoluble in water, although homogeneous solutions (either the hydrated form or the polyacetal?) are formed when the (II) compounds are hydrolyzed.

Found %: C 17.96, 18.14; H 2.04, 2.24; Br 72.78, 73.05. $C_3H_4OBr_2$. Calculated %: C 16.76; H 1.86; Br 74.02.

The p-nitrophenylhydrazone was obtained by mixing an alcohol solution of 0.5 g of β,β-dibromopropionaldehyde with a water solution of 0.5 g of p-nitrophenylhydrazine hydrochloride. Yield 0.45 g, m.p. 80-82° (decomp.).

Found %: N 11.79, 11.68. $C_9H_9O_2N_3Br_2$. Calculated %: N 11.97.

The compound decomposes when its recrystallization is attempted; when kept in the air it changes rapidly with the evolution of hydrogen bromide.

Dimedon derivative, m.p. 119-120°.

Found %: Br 33.36, 33.37. $C_{19}H_{26}O_4Br_2$. Calculated %: Br 33.47.

The bisulfite derivative was obtained by shaking an alcohol solution of the aldehyde with a water solution of sodium metabisulfite; the properties and analysis results correspond with those described above.

Semicarbazone. A water solution of 0.25 g of semicarbazide hydrochloride and 0.35 g of sodium acetate was added gradually to a solution of 0.5 g of the aldehyde in alcohol. We obtained 0.55 g of the semicarbazide with m.p. 124.5-126° (decomp.).

Found %: N 15.63, 15.69. $C_4H_7ON_3Br_2$. Calculated %: N 15.38.

After recrystallization from aqueous alcohol, a sample of the semicarbazone was allowed to stand in the air for several hours, and here we obtained a substance with m.p. 138.5° (decomp.), which from the analysis results is the semicarbazone of β-bromoacrolein.

Found %: N 22.07, 22.06. $C_4H_6ON_3Br$. Calculated %: N 21.87.

Oxidation of β,β-dichloropropionaldehyde. β,β-Dichloropropionaldehyde (3.2 g) was added slowly to 5 ml of nitric acid (d 1.48). A copious evolution of nitrogen oxides began within 30 minutes. The next day the mixture was cautiously heated on the water bath for seven hours until all of the nitrogen oxides had been removed, after which it was diluted with water, and then extracted with ether and methylene chloride. The residue after evaporating the solvents was fractionally distilled in vacuo. We obtained 1.5 g (41%) of β,β-dichloropropionic acid with b.p. 76-78° (1.5 mm), which crystallized completely on cooling; m.p. 54.5-55° (from petroleum ether) [3].

SUMMARY

The new β,β-dichloro- and β,β-dibromopropionaldehydes were obtained by the hydrolysis of 1,1,3-trihalo-3-alkoxypropanes under mild conditions and their properties were characterized. The derivatives of these aldehydes easily lose hydrogen halide, being converted to the corresponding β-haloacrolein derivatives.

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N-ARYLSULFONAMIDE DERIVATIVES OF DIETHANOLAMINE

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Substituted ethanolamines have received much discussion in the literature, especially in review papers and monographs. The arylsulfonamide derivatives of monoethanolamine and diethanolamine have hardly been studied.

The purpose of the present investigation was to synthesize and study the properties of the indicated type of compounds, and first those derived from diethanolamine and arylsulfonyl chlorides.

$$ArSO_2Cl + 2HN(CH_2CH_2OH)_2 \rightarrow ArSO_2N(CH_2CH_2OH)_2 + HCl \cdot HN(CH_2CH_2OH)_2$$

The N,N-bis(2-hydroxyethyl)arylsulfonamides formed according to this reaction, as well as their derivatives, should undoubtedly possess practical interest. From the literature it is known that the neutral esters of these compounds, as well as the esters of N-alkyl-N-(2-hydroxyethyl)arylsulfonamides, have been suggested useful as plasticizers and waxes [1, 2].

N,N-Bis(2-hydroxyethyl)-p-toluenesulfonamide was synthesized from ethylene chlorohydrin and the sodium derivative of p-toluenesulfonamide, going through N-(2-hydroxyethyl)-p-toluenesulfonamide. Here the product was obtained in 18% yield as a slowly crystallizing viscous sirup [3]. Some information is given in one of the patents on the preparation of N,N-bis(2-hydroxyethyl)-p-toluenesulfonamide and N,N-bis(2-hydroxyethyl)-2-naphthalenesulfonamide from diethanolamine and the proper arylsulfonyl chloride in the presence of aqueous soda solution [2]. The compounds obtained using this method frequently differ in their properties from those synthesized by us.

We synthesized the following N,N-bis(2-hydroxyethyl)arylsulfonamides:

$$ArSO_2N(CH_2CH_2OH)_2$$

(I) Ar = C_6H_5, (II) Ar = C_6H_4Cl-p, (III) Ar = $C_6H_4NO_2$-p, (IV) Ar = $C_6H_4CH_3$-p, (V) Ar = $C_6H_4CH_3$-o; (VI) Ar = $C_6H_3ClNO_2$-1, 2, (VII) Ar = β-$C_{10}H_7$.

To synthesize N,N-bis(2-hydroxyethyl)benzenesulfonamide and N,N-bis(2-hydroxyethyl)-p-chlorobenzenesulfonamide we first used the method of heating equimolar amounts of the sulfonyl chloride and amine in the presence of one equivalent of aqueous caustic solution [4]. However, we were unable to obtain the desired products with this procedure. In the case of benzenesulfonyl chloride we isolated a substance with m.p. 128°, apparently of the same composition as $(C_6H_5SO_2OCH_2CH_2)_2NSO_2C_6H_5$, as the calculated N for this compound is 2.66%, while the obtained product had 2.8% N.

The attempted synthesis of diethanolamine derivatives of arylsulfonamides from equimolar amounts of diethanolamine and the proper arylsulfonyl chloride in the presence of pyridine (based on the well-known reaction [1, 5]) also gave negative results.

In the case of p-chlorobenzenesulfonyl chloride we isolated here a pure high-melting, nitrogen-free compound, in its composition corresponding to the sodium salt of p-chlorobenzenesulfonic acid. Only N,N-bis(2-hydroxyethyl)-2-naphthalenesulfonamide was obtained with this procedure in 25% of the theoretical yield.

The other compounds were synthesized by a new method, based on the reaction of a double amount of diethanolamine with the proper arylsulfonyl chloride in the absence of a base, with refluxing in o-xylene for five hours.

With the exception of the o-toluenesulfonamide derivative, the N,N-bis(2-hydroxyethyl)arylsulfonamides are crystalline compounds. They are all insoluble in alkalies, in cold water and in petroleum ether, are easily soluble in acetone and alcohol, soluble in boiling benzene, and slightly soluble in carbon tetrachloride. They were purified by recrystallization from a suitable solvent.

To prove the structure of the synthesized compounds we studied some of their chemical properties, and specifically the preparation of the chlorides and bromides. We used thionyl chloride [3] to replace the hydroxyl group by chlorine, since the other methods examined proved to be less suitable. To replace the hydroxyl group by bromine we reacted a solution of the N,N-bis(2-hydroxyethyl)arylsulfonamide with gaseous hydrogen bromide.

The following halo derivatives of N,N-bis(2-hydroxyethyl)arylsulfonamides were prepared:

$$ArSO_2N(CH_2CH_2X)_2$$

(VIII) Ar = C_6H_5, X = Cl; (IX) Ar = C_6H_4Cl-*n*, X = Cl; (X) Ar = $C_6H_4CH_3$-*o*, X = Cl;
(XI) Ar = C_6H_5, X = Br; (XII) Ar = $C_6H_4NO_2$-*p*, X = Br.

All of the obtained halo derivatives of N,N-bis(2-hydroxyethyl)arylsulfonamides are crystalline compounds. They are insoluble in water, readily soluble in acetone, carbon tetrachloride and benzene and more difficultly soluble in alcohol and petroleum ether. The bromides attack the mucous membranes of the eyes and nose.

EXPERIMENTAL

Reaction of Diethanolamine with Arylsulfonyl Chlorides

A. A mixture of 0.05 mole of arylsulfonyl chloride, 0.11 mole of diethanolamine and 25-30 ml of o-xylene was boiled for five hours in a flask fitted with a reflux condenser and mechanical stirrer. The reaction mass after cooling was removed from the flask, and the o-xylene solution was separated in a separatory funnel (a precipitate was obtained in the case of p-chlorobenzenesulfonyl chloride, which was filtered and treated with 10% sodium hydroxide solution). The residual sirupy liquid was treated with 10% sodium hydroxide solution and the obtained precipitate was filtered. In the case of the benzene-, p-toluene- and o-toluenesulfonyl chlorides, an emulsion was formed with the caustic solution, which had to be decomposed with acid, and then the compound was separated in conventional manner. The precipitate was filtered, dried and recrystallized. The compounds obtained as viscous oils were washed with water, dissolved in acetone, the solution dried over fused potash, and the acetone vacuum-distilled. The derivative, obtained from benzenesulfonyl chloride in this manner, crystallized after standing for ten days.

To obtain an accurate accounting of the reaction products, the alkaline filtrate was acidified under cooling with concentrated hydrochloric acid until acid to Congo, then evaporated in vacuo, the residue dissolved in a mixture of alcohol and acetone, the sodium chloride separated, and the solvents removed by vacuum-distillation. The residual thick, colored liquid contained excess diethanolamine and secondary reaction products, which were not investigated. The xylene was removed from the o-xylene solution by vacuum-distillation.

The following compounds were synthesized with the indicated procedure:

N,N-Bis(2-hydroxyethyl)benzenesulfonamide (I), yield 74.3%, m.p. 60-64° (from carbon tetrachloride).

Found %: N 5.76. $C_{10}H_{15}O_4NS$. Calculated %: N 5.71.

N,N-Bis(2-hydroxyethyl)-p-chlorobenzenesulfonamide (II), yield 79.9%, colorless scales, m.p. 88-89° (from benzene).

Found %: N 5.10. $C_{10}H_{14}O_4NSCl$. Calculated %: N 5.00.

N,N-Bis(2-hydroxyethyl)-p-nitrobenzenesulfonamide (III), yield 32.2%, yellow crystals with m.p. 128-130° (from n-butyl alcohol).

Found %: N 9.30. $C_{10}H_{14}O_6N_2S$. Calculated %: N 9.60.

N,N-Bis(2-hydroxyethyl)-p-toluenesulfonamide (IV), yield 84.9%, colorless crystals with m.p. 101.5-103° (from water).

Found %: N 5.60. $C_{11}H_{17}O_4NS$. Calculated %: N 5.40.

N,N-Bis(2-hydroxyethyl)-o-toluenesulfonamide (V), yield 94.6%, clear amber sirup.

Found %: N 5.66. $C_{11}H_{17}O_4NS$. Calculated %: N 5.40.

N,N-Bis(2-hydroxyethyl)-1,2-chloronitrobenzenesulfonamide (VI), yield 21%, yellow crystals, m.p. 145-146° (from ethanol).

Found %: N 8.63; S 10.40. $C_{10}H_{13}O_6N_2ClS$. Calculated %: N 8.62; S 9.86.

To increase the yield of N,N-bis(2-hydroxyethyl)-1,2-chloronitrobenzenesulfonamide we ran experiments in which the time of heating in o-xylene was increased to ten hours, and also experiments in which the 1,2-chloronitrobenzenesulfonamide was added slowly in drops to the reaction sphere. These experiments failed to improve the results.

B. A mixture of 0.05 g-mole of 2-naphthalenesulfonyl chloride, 0.05 g-mole of diethanolamine, 4.0 ml of anhydrous pyridine and 25 ml of o-xylene was boiled for five hours in a flask fitted with a reflux condenser and mechanical stirrer. The reaction mixture was worked up in conventional manner. The condensation product was isolated from solution after distilling off the solvents in vacuo. The N,N-bis(2-hydroxyethyl)-2-naphthalenesulfonamide (VII) (yield 25%) was recrystallized from petroleum ether, m.p. 135-138°.*

Found %: N 4.55. $C_{14}H_{17}O_4NS$. Calculated %: N 4.74.

Preparation of Halo Derivatives

To prepare the chloro derivatives the N,N-bis(2-hydroxyethyl)arylsulfonamide (I – 0.004 g-mole, II – 0.0107 g-mole, V – 0.015 g-mole) was charged into a small reaction flask fitted with stirrer, dropping funnel, thermometer and reflux condenser, and then thionyl chloride (respectively, 0.0096, 0.026 and 0.037 g-mole) was added in drops and with good cooling. The temperature of the reaction mixture was not allowed to exceed 10°. After all of the thionyl chloride had been added, the stirring and cooling was continued for another four hours, after which the reaction mixture was allowed to stand overnight. The next day the mixture was heated at 60-70° for two hours, and at 100° for one hour. Then the reaction mixture was cooled and poured into cold water. The solid product was filtered, washed thoroughly with water, dried and recrystallized. A viscous liquid was obtained from N,N-bis(2-hydroxyethyl)-o-toluenesulfonamide, which failed to solidify on long cooling. The liquid was washed with water, dissolved in benzene, the solution dried over anhydrous sodium sulfate, and the benzene vacuum-distilled. The yield of pure chloride was 22.1%. After recrystallization from petroleum ether, N,N-bis(2-chloroethyl)benzenesulfonamide (VIII) had m.p. 47-48° [6].

Found %: N 5.03. $C_{10}H_{13}O_2NCl_2S$. Calculated %: N 4.96.

N,N-Bis(2-chloroethyl)-p-chlorobenzenesulfonamide (IX), yield 18.0%, m.p. 84-85° (from petroleum ether) [6].

Found %: S 10.35; Cl 33.52. $C_{10}H_{12}O_2NCl_3S$. Calculated %: S 10.11; Cl 33.64.

N,N-Bis(2-chloroethyl)-o-toluenesulfonamide was obtained as a dark-yellow sirup. The yield of technical chloride was 51.75%.

Found %: Cl 22.90. $C_{11}H_{15}O_2NCl_2S$. Calculated %: Cl 23.90.

To synthesize the bromo derivatives we dissolved 0.004 g-mole of N,N-bis(2-hydroxyethyl)benzenesulfonamide in 10 ml of hydrobromic acid, and 0.0008 g-mole of N,N-bis(2-hydroxyethyl)-p-nitrobenzenesulfonamide in 10 ml of o-xylene; gaseous hydrogen bromide was then passed through the respective solutions for two hours with heating (on the boiling-water bath), after which the reaction mixtures were allowed to stand overnight. The bromide formed in the first experiment was filtered, washed thoroughly with water, dried, and recrystallized from methyl alcohol. To isolate the second bromide the o-xylene solution was evaporated in vacuo; the residue washed with water, dried, and then recrystallized from methyl alcohol.

N,N-Bis(2-bromoethyl)benzenesulfonamide (XI) was obtained in 35.4% yield, and had m.p. 94-95°.

Found %: Br 44.33. $C_{10}H_{13}O_2NBr_2S$. Calculated %: Br 43.96.

*From the literature [2]: m.p. 92-94°.

N,N-Bis(2-bromoethyl)-p-nitrobenzenesulfonamide (XII) was obtained in 31.0% yield, and had m.p. 152-153°.

Found %: S 7.32. $C_{10}H_{12}O_4N_2Br_2S$. Calculated %: S 7.69.

The obtained yields of the bromides cannot be considered as being the maximum, since the losses incurred in working with small amounts of materials were relatively great.

SUMMARY

1. The condensation of diethanolamine with arylsulfonyl chlorides was investigated, and a new method for the synthesis of N,N-bis(2-hydroxyethyl)arylsulfonamides was proposed.

2. It was shown that in the presence of aqueous caustic, or of pyridine, the reaction to give N,N-bis(2-hydroxyethyl)arylsulfonamides either does not go or it leads to the formation of quite impure products.

3. Ten new arylsulfonamide derivatives were synthesized and characterized.

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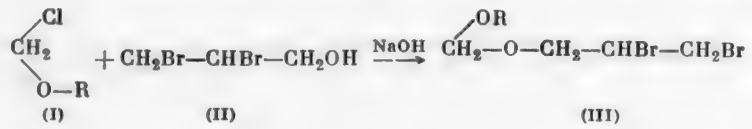
ETHERS OF GLYCOLS AND THEIR DERIVATIVES

XXXV. SYNTHESIS OF β,γ-DIBROMO DERIVATIVES OF ETHERS OF METHYLENE GLYCOL

Shamkhal Mamedov and D. Khydyrov

One of us had proposed a method for the synthesis of both symmetrical and unsymmetrical methylene glycol ethers [1].

In this paper the method was applied to the preparation of the β,γ-dibromo derivatives of methylene glycol ethers, which, as is known from the literature, have remained completely unstudied. The reaction can be depicted by the scheme.



(I) (II) (III)

β,γ-Dibromopropyl alcohol (II) has received little study, and the data given in the literature regarding its nature and constants are contradictory [2].

Our experiments on the matter revealed that the β,γ-dibromopropyl alcohol obtained by us under the generally known conditions [3-9], also used by V.D. Iasnopol'skii in his attempted preparation of the alcohol [2], contrary to the data given by Iasnopol'skii, distills at 213-214° at atmospheric pressure, with considerable decomposition. The constants of the pure product, obtained by vacuum-distillation, are quite different from those given in Iasnopol'skii's paper.

In his paper, Iasnopol'skii states that the reaction of the β,γ-dibromopropyl alcohol obtained by him with benzoyl chloride enabled him to obtain the benzoate of β,γ-dibromopropyl alcohol (V) with m.p. 86-88°. However, he failed to support his conclusions by any analytical data, limiting himself only to a melting point determination of the obtained product. For this reason we decided to repeat this portion of V.D. Iasnopol'skii's work, and must confess that all of the conclusions given by Iasnopol'skii in the indicated paper are entirely different from the actuality.

Further, Iasnopol'skii writes that he was able to synthesize a new cyclic ester from the β,γ-dibromopropyl benzoate obtained by him. However, verification of the author's data (0.1310 g substance, 21.25 g benzene, Δ^t 0.174°) revealed that he made an error in the calculations, for the molecular weight found by the author is actually equal to 182.2, and not 321.6, as given in the paper for the cyclic ester.

We were able to synthesize β,γ-dibromopropyl benzoate (V) by reacting benzoyl chloride with β,γ-dibromopropyl alcohol, and the compound proved to be an oily liquid, and not the crystalline product with m.p. 86-88°, as indicated by V. Iasnopol'skii.

The composition of the dibromo ester (V) obtained by us was established by complete elemental analysis and determination of the molecular weight, while the structure was established by saponification with alkali.

In addition, to verify the obtained data, we synthesized β,γ-dibromopropyl benzoate (V) by the bromination of allyl benzoate (IV) in the cold.

$$\underset{\text{(IV)}}{C_6H_5COOCH_2—CH=CH_2} \xrightarrow{Br_2} \underset{\text{(V)}}{C_6H_5COOCH_2—CHBr—CH_2Br}$$

The constants of the esters, obtained by the two methods, showed complete agreement.

Consequently, the reported synthesis of a cyclic ester (ester of 1-hydroxymethylcyclopropane-2,2-dicarboxylic acid) by V. Iasnopol'skii also proved to be erroneous, since the starting material that the author used in the Perkin synthesis was actually not suitable.

Having answered some of the questions connected with β,γ-dibromopropyl alcohol (being the starting material in our subsequent syntheses), we synthesized a number of alkyl β,γ-dibromopropyl ethers of methylene glycol (III), this being the main purpose of our study, and established that these ethers are readily obtained in 40% yield by reacting α-chloro ethers (I) with β,γ-dibromopropyl alcohol (II) in anhydrous benzene in the presence of 70% NaOH. The composition of the synthesized dibromo ethers (III) was shown by their complete analysis, while the structure was shown by hydrolysis, which led to the formation of β,γ-dibromopropyl alcohol, formaldehyde and the corresponding alcohols.

To verify the obtained data we synthesized the dibromo ethers (III) by the bromination of the unsaturated alkyl allyl ethers of methylene glycol (VI) in the cold.

$$\underset{\text{(VI)}}{CH_2(OR)—OCH_2—CH=CH_2} \xrightarrow{Br_2} \underset{\text{(III)}}{CH_2(OR)—OCH_2—CHBr—CH_2Br}$$

The constants of the dibromo ethers, obtained by the two methods, showed complete agreement.

EXPERIMENTAL

Synthesis of β,γ-dibromopropyl alcohol (II). Bromine (100 g) was added in drops, with vigorous stirring and cooling (ice + salt), to 36 g of allyl alcohol. After washing and drying, the reaction products were fractionally distilled in vacuo to give 108 g (80%) of β,γ-dibromopropyl alcohol (II).

B.p. 213-214° (decomp.), 117-119° (17 mm), d_4^{20} 2.1569, n_D^{20} 1.5625, MR_D 32.8; calc. 33.11.

Literature [3, 8, 10]: b.p. 118° (17 mm), 219° (decomp.), d°* 2.1682.**

Found %: C 17.17; H 2.93; Br 73.42. $C_3H_6OBr_2$. Calculated %: C 16.52; H 2.75; Br 73.39.

Synthesis of β,γ-dibromopropyl benzoate (V). A mixture of 145 g of benzoyl chloride, 218 g of β,γ-dibromopropyl alcohol and 300 g of anhydrous benzene was treated dropwise with 60 ml of 70% NaOH (in 35 minutes), with stirring and cooling (ice + salt). The stirring was continued for two hours with cooling and then for 30 minutes at 60-70°. After washing, drying and removal of the solvent we obtained 206 g of an oily liquid, from which we obtained 180 g (56%) of β,γ-dibromopropyl benzoate (V) by two vacuum-distillations.

B.p. 155-157° (4 mm), f.p. −18°; d_4^{20} 1.6890, n_D^{20} 1.5692, MR_D 62.48; calc. 61.96.

Found %: C 37.23, 37.25; H 3.17, 3.20; Br 49.05, 49.30. M 321.4. $C_{10}H_{10}O_2Br_2$. Calculated %: C 37.26; H 3.11; Br 49.69. M 322.

Synthesis of allyl benzoate (IV). A 50% NaOH solution (90 g) was added with stirring at room temperature to a mixture of 58 g of allyl alcohol, 147 g of benzoyl chloride and 200 ml of anhydrous benzene. After the usual workup we obtained 89 g (55%) of allyl benzoate (IV).

B.p. 118-120° (21 mm), d_4^{20} 1.0556, n_D^{20} 1.5192, MR_D 46.62; calc. 45.97.

Literature [11]: b.p. 228°, d_4^4 1.0671, d_{15}^{15} 1.0578.

Found %: C 73.82, 73.77; H 6.27, 6.30. $C_{10}H_{10}O_2$. Calculated %: C 74.07; H 6.17.

*As in original – Publisher's note.

**The constants given in V. Iasnopol'skii's paper [2] for β,γ-dibromopropyl alcohol (b.p. 205.5-206°, d_4^{20} 1.8960; n_D^{20} 1.5360) do not agree with either the literature or our data.

Alkyl β,γ-Dibromopropyl Ethers of Methylene Glycol (III)

Compound No.	Structure and name of obtained ethers	Boiling point and pressure (in mm)	d_4^{20}	n_D^{20}	MR_D		Amount (in %)						Yield (in %)
							C		H		Br		
					found	calc.	found	calc.	found	calc.	found	calc.	
1	$CH_2(OCH_3)-O-CH_2-CHBr-CH_2Br$ Methyl-β,γ-dibromopropyl ether of methylene glycol	129—130.5° (34)	1.7776	1.5074	43.90	44.11	—	—	—	—	61.41, 61.46	61.07	38
2	$CH_2(OC_4H_9)-OCH_2-CHBr-CH_2Br$ Butyl-β,γ-dibromopropyl ether of methylene glycol	117—118 (3)	1.5136	1.4904	58.13	57.96	32.10, 31.29	31.58	5.42, 5.28	5.26	52.21, 52.28	52.63	40
3	$CH_2(OC_5H_{11}\text{-iso})-OCH_2-CHBr-CH_2Br$ Isoamyl-β,γ-dibromopropyl ether of methylene glycol	119—120 (4)	1.4532	1.4860	62.83	62.58	—	—	—	—	50.03, 50.23	50.32	42

Bromination of allyl benzoate (IV). Bromine (24 g) was added with strong cooling (−15°) and stirring to a solution of 24 g of the benzoate in 100 ml of anhydrous ether. After washing, drying and removal of the solvent by distillation we obtained 38.5 g (80%) of β,γ-dibromopropyl benzoate (V).

B.p. 150-151° (3 mm), d_4^{20} 1.6865, n_D^{20} 1.5704, MR_D 62.69. $C_{10}H_{10}O_2Br$. Calculated 61.96.

Saponification of β,γ-dibromopropyl benzoate (V). A mixture of 8.5 g of benzoate (V) and 20 ml of 20% KOH was heated for one hour, after which the mixture was acidified with dilute hydrochloric acid. We obtained 2 g of benzoic acid and 2.5 g of unchanged β,γ-dibromopropyl benzoate.

Synthesis of butyl β,γ-dibromopropyl ether of methylene glycol. A mixture of 88 g of β,γ-dibromopropyl alcohol (II), 53 g of α-chloromethyl butyl ether, obtained by the Litterscheid procedure [12], and 150 g of anhydrous benzene was treated with 40 ml of 50% NaOH solution at 20° and with vigorous stirring. After washing, drying and removal of the benzene by distillation we obtained 49 g (40%) of the butyl β,γ-dibromopropyl ether of methylene glycol, the constants of which are given in the Table (Compound 2).

We also isolated 10 g of the dibutyl ether of methylene glycol from the reaction products, while 3 g of a heavy tarry product remained in the distillation flask. Using similar conditions we synthesized two other new ethers, the constants of which are given in the Table.

Synthesis of butyl allyl ether of methylene glycol (VI). This unsaturated ether was synthesized using the alkaline method of synthesizing glycol ethers [1].

B.p. 75-77° (40 mm), d_4^{20} 0.8488, n_D^{20} 1.4102, MR_D 42.05. $C_8H_{16}O_2$. Calc. 41.97.

Found %: C 66.50; H 11.13. M 143.8. $C_8H_{16}O_2$. Calculated %: C 66.67; H 11.11. M 144.

Bromination of butyl allyl ether of methylene glycol (VI). The bromination was run by the method described above. We obtained 23.5 g (55%) of the butyl β,γ-dibromopropyl ether of methylene glycol, the constants of which showed complete agreement with the data given in the Table (Compound 2).

Hydrolysis of the butyl β,γ-dibromopropyl ether of methylene glycol (III). The hydrolysis of 19.7 g of dibromo ether (III) was run in conventional manner. From the hydrolysis we isolated 2 g of butyl alcohol and 10 g of β,γ-dibromopropyl alcohol (V). The black residue in the distillation flask weighed 1 g.

SUMMARY

1. It was established that the β,γ-dibromopropyl derivatives of methylene glycol ethers can be synthesized by the alkaline method of synthesizing glycol ethers.

2. A method was proposed for the synthesis of the β,γ-dibromopropyl derivatives of methylene glycol ethers by the bromination of the alkyl allyl ethers of methylene glycol.

3. Three new β,γ-dibromopropyl derivatives of methylene glycol ethers were synthesized and some of their properties were studied.

4. The constants given in the literature [2] for β,γ-dibromopropyl alcohol and β,γ-dibromopropyl benzoate were corrected.

5. Two different methods were offered for the synthesis of β,γ-dibromopropyl benzoate.

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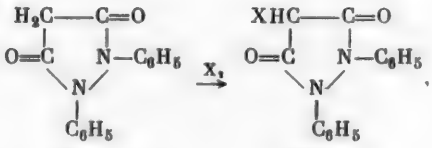
CHEMISTRY OF PYRAZOLIDINE

II. HALOGENATION AND THIOCYANATION OF 1,2-DIPHENYL-3,5-DIOXOPYRAZOLIDINE AND ITS DERIVATIVES

V.G. Pesin, A.M. Khaletskii and Teng Jun-hsiang

Whereas pyrazolones have been studied in considerable detail, the structurally similar pyrazolidine ring has received very little attention; thus, for example, the mechanism of the halogenation or thiocyanation of the latter remains obscure. As our investigations had shown, 1,2-diphenyl-3,5-dioxopyrazolidine (I) readily reacts with chlorine, bromine and thiocyanogen to form the corresponding monochloro, bromo and thiocyanato derivatives (II). The reaction goes both with cooling and at room temperature, without the use of catalysts, according to the scheme

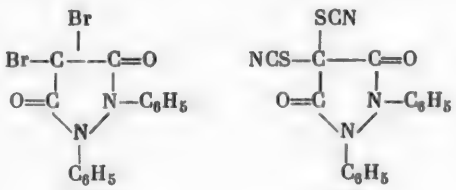


(I) (II)

where X = Cl, Br or CNS.

For the chlorination we used chlorine gas and chloroform as the solvent, while the bromination was run using bromine and again chloroform as the solvent (the bromination was run with cooling). The thiocyanation was run at 0-2° using thiocyanogen, obtained by the reaction of bromine with ammonium thiocyanate in methanol that had been saturated with ammonium bromide [1]. The high reactivity shown by the hydrogens at C_4 in the pyrazolidine ring, observed during halogenation and thiocyanation, permitted us to conclude that it is possible to halogenate (brominate) 1,2-diphenyl-3,5-dioxopyrazolidine (I) without the use of ultraviolet, as had recently been described in the literature [2].

Only the 4-monochloro derivative is formed when a chloroform solution of 1,2-diphenyl-3,5-dioxopyrazolidine is saturated with chlorine either in the cold or at chloroform boil, or when the chlorination is run in a melt (at 100-105°). In contrast to this, bromination using two moles of bromine yields the 4,4-dibromo derivative (III). The dithiocyanato derivative (IV) is also easily formed when the pyrazolidine is reacted with two moles of thiocyanogen.



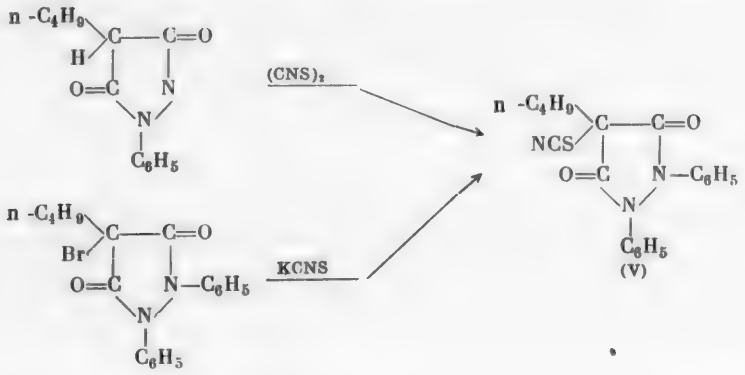
(III) (IV)

In order to determine the effect of a substituent at C_4 on the entrance of a halogen or pseudohalogen (thiocyanogen) into the pyrazolidine molecule, we investigated the halogenation and thiocyanation of 4-n-butyl-1,2-

diphenyl-3,5-dioxopyrazolidine, i.e., when one of the hydrogens at C_4 was replaced; here it was established that the n-butyl radical is practically without influence on the mechanism of the reaction.

4-Chloro-4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine was obtained under the same conditions used to chlorinate 1,2-diphenyl-3,5-dioxopyrazolidine; 4-bromo-4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine was synthesized by the bromination of 4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine in boiling chloroform.

4-Thiocyanato-4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine (V) was obtained by two routes: a) by the thiocyanation of 4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine, analogous to the thiocyanation of 1,2-diphenyl-3,5-dioxopyrazolidine, and b) the reaction of 4-bromo-4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine with potassium thiocyanate in boiling alcohol.



Both in the case of 1,2-diphenyl-3,5-dioxopyrazolidine and its 4-n-butyl derivative it is the hydrogen of the methylene group that is replaced by chlorine, bromine or the thiocyanato radical during halogenation and thiocyanation; replacement of the hydrogens of the aromatic ring is less probable here. This follows from the fact that the chlorine, bromine or thiocyanato radical of the corresponding halo or thiocyanato pyrazolidines show easy exchange reaction. The same is also indicated by the fact that 1,2-diphenyl-3,5-dioxopyrazolidine and its 4-halo derivative are readily soluble in alkalies, whereas the 4,4-dihalo- or the 4-halo-4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidines are insoluble in alkalies.

EXPERIMENTAL

1,2-Diphenyl-3,5-dioxopyrazolidine. To a solution of 4.6 g of sodium in 100 ml of anhydrous alcohol was added 32 g of malonic ester and 21.22 g of hydrazobenzene. The reaction mixture was boiled with constant stirring in a three-necked flask, fitted with a reflux condenser and calcium chloride tube, until a homogeneous mass was obtained. Then the reflux condenser was replaced by a descending condenser, and with constant stirring the alcohol was distilled off until the temperature of the reaction mixture reached 180-200°. The reaction mass after cooling was treated with 200 ml of water, the alkaline filtrate extracted with ether, and then it was acidified with dilute hydrochloric acid. The precipitate after washing with water and recrystallization from alcohol gave 45.4 g (90%) of a substance with m.p. 173.5°, from its melting point and other properties corresponding to 1,2-diphenyl-3,5-dioxopyrazolidine, described in the literature [3].

4-Chloro-1,2-diphenyl-3,5-dioxopyrazolidine. Chlorine was passed for one hour into a solution of 1 g of 1,2-diphenyl-3,5-dioxopyrazolidine in 10 ml of chloroform at room temperature, and here a slight amount of exothermic heat was observed. The reaction product was poured into a porcelain dish, and the chloroform was evaporated in the air; the residue was a viscous yellow oil that soon crystallized. After recrystallization from benzene we obtained 1.02 g (90%) of a substance with m.p. 113-114.5°. The compound was obtained as white crystals, readily soluble in alkalies, chloroform, alcohol, ether, carbon tetrachloride and acetone, and insoluble in water and acids.

Found %: C 62.75, 63.08; H 3.60, 3.90; N 9.45, 9.66. $C_{15}H_{11}O_2N_2Cl$. Calculated %: C 62.83; H 3.84; N 9.77.

4-Bromo-1,2-diphenyl-3,5-dioxopyrazolidine. A solution of 4.7 g of bromine in 20 ml of chloroform was

added gradually from a dropping funnel to a solution of 6 g of 1,2-diphenyl-3,5-dioxopyrazolidine in 50 ml of chloroform with cooling and constant stirring; here the separation of pale-yellow crystals was observed, which gradually went into solution. The solution was stirred for four hours, then washed with water until neutral, dried over fused sodium sulfate, the chloroform vacuum-distilled, the residue extracted with petroleum ether, and after removal of the solvent by vacuum-distillation we obtained 6.4 g of a substance with m.p. 50-55°, from its melting point and other properties corresponding to 4-bromo-1,2-diphenyl-3,5-dioxopyrazolidine, described in the literature [2].

4-Thiocyanato-1,2-diphenyl-3,5-dioxopyrazolidine. A solution of 1.4 g of bromine in 25 ml of methanol, saturated with ammonium bromide, was added from a dropping funnel, with cooling and stirring, to a mixture of 1 g of 1,2-diphenyl-3,5-dioxopyrazolidine, 1.8 g of ammonium thiocyanate and 25 ml of methanol. After stirring for one hour the reaction mixture was filtered, the filtrate treated with 100 ml of water, and the obtained precipitate was suction-filtered, washed with water, and dried. We obtained 1.08 g (80%) of a substance which, after recrystallization from alcohol, had m.p. 175-180° (with decomp.). The compound was obtained as white, lustrous plates, soluble in water, methanol and ethanol, and insoluble in ether, chloroform and in acids; the compound is soluble in caustic alkalies.

Found %: C 62.24, 62.38; H 3.59, 3.67; N 13.67, 13.65. $C_{16}H_{11}O_2N_3S$. Calculated %: C 62.14; H 3.59; N 13.60.

4,4-Dibromo-1,2-diphenyl-3,5-dioxopyrazolidine. A solution of 5 g of bromine in 20 ml of chloroform was added, with heating on the water bath and constant stirring, to a solution of 3 g of 1,2-diphenyl-3,5-dioxopyrazolidine in 50 ml of chloroform. The reaction solution was stirred for one hour, then washed with water until neutral, dried over fused sodium sulfate, the chloroform evaporated in the air, and the residue recrystallized from alcohol; we obtained 3.2 g of a substance with m.p. 136-138° (65.04%).

Found %: C 44.29, 44.01; H 2.73, 2.44; N 6.74, 7.04. $C_{15}H_{10}O_2N_2Br_2$. Calculated %: C 43.90; H 2.44; N 6.83.

4,4-Dithiocyanato-1,2-diphenyl-3,5-dioxopyrazolidine. When the reaction was run the same as described for the preparation of 4-thiocyanato-1,2-diphenyl-3,5-dioxopyrazolidine, but with half the amount of 1,2-diphenyl-3,5-dioxopyrazolidine, we observed that only a small amount of precipitate separated when the filtrate was treated with 100 ml of water. Acidification of the filtrate with dilute hydrochloric acid gave a copious precipitate, which was soluble in water and in alcohol; recrystallization from 60° alcohol gave 1.14 g (80%) of crystals with m.p. 154-156°, insoluble in both acids and alkalies.

Found %: C 55.70, 56.17; H 3.09, 2.98; N 15.25, 14.76. $C_{17}H_{10}O_2N_4S_2$. Calculated %: C 55.74; H 2.73; N 15.30.

4-Chloro-4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine. A stream of chlorine was passed for one hour into a solution of 1 g of 4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine in 10 ml of chloroform at room temperature (here a slight evolution of heat was observed). The reaction mixture was poured into a porcelain dish, the chloroform allowed to evaporate spontaneously, and the residue recrystallized from alcohol to give 0.95 g (85%) of a substance with m.p. 100-101.5°. The compound was obtained as white crystals, soluble in alcohol, and insoluble in water, alkalies and acids.

Found %: C 66.43, 66.64; H 5.57, 5.41; N 8.16, 8.55. $C_{19}H_{19}O_2N_2Cl$. Calculated %: C 66.57; H 5.55; N 8.18.

4-Bromo-4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine. A solution of 1.6 g of bromine in 10 ml of chloroform was added slowly in one hour, with constant stirring, to a solution of 3 g of 4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine in 30 ml of chloroform at 60-70°. After washing with water, the chloroform layer was separated, dried over fused sodium sulfate, and the solvent allowed to evaporate in the air; recrystallization from alcohol gave 3.2 g (84%) of a substance with m.p. 116-118°, from its melting point and other properties corresponding to 4-bromo-4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine, described in the literature [4].

4-Thiocyanato-4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine. A solution of 1.2 g of bromine in 25 ml of methanol, saturated with ammonium bromide, was added in one hour and with constant stirring to a mixture of 2 g 2 g of 4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine, 1.5 g of ammonium thiocyanate and 25 ml of methanol; here the 4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine went into solution. The addition of 100 ml of water to the reaction mass gave an oily liquid that soon crystallized, and after recrystallization from alcohol we obtained

2.16 g (90%) of a substance with m.p. 105-106°. The compound was obtained as white lustrous plates, insoluble in water, alkalies and acids, and soluble in alcohol, ether and chloroform.

Found %: C 65.71, 65.44; H 5.80, 5.24; N 11.77, 11.62. $C_{20}H_{19}O_2N_2S$. Calculated %: C 65.75; H 5.21; N 11.51.

Study of the reaction of 4-bromo-4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine with potassium thiocyanate. 4-Bromo-4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine (1.5 g) was added gradually to a solution of 0.5 g of potassium thiocyanate in 20 ml of anhydrous alcohol; here a precipitate separated immediately. After refluxing for four hours the precipitate was filtered, washed with water and dried to give 1.4 g of a substance with m.p. 103-104°, from its melting point, analysis and other properties corresponding to 4-n-butyl-4-thiocyanato-1,2-diphenyl-3,5-dioxopyrazolidine, identical with that obtained earlier by the direct thiocyanation of 4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine. The mixed melting point with an authentic specimen was not depressed.

SUMMARY

1. The reaction of halogens (chlorine, bromine), and also of a pseudohalogen (thiocyanogen), with 1,2-diphenyl-3,5-dioxopyrazolidine was investigated, in which connection the corresponding 4-chloro, 4-bromo and 4-thiocyanato derivatives of 1,2-diphenyl-3,5-dioxopyrazolidine were isolated.

2. It was shown that the reaction of a double amount of halogen or of pseudohalogen (thiocyanogen) with 1,2-diphenyl-3,5-dioxopyrazolidine yields the 4,4-dibromo and 4-4-dithiocyanato derivatives of 1,2-diphenyl-3,5-dioxopyrazolidine (we were unable to isolate 4,4-dichloro-1,2-diphenyl-3,5-dioxopyrazolidine).

3. It was found that the chlorination, bromination or thiocyanation of 4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine yields the corresponding 4-chloro, 4-bromo and 4-thiocyanato derivatives of 4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine.

4. It was found that 4-bromo-4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine reacts with potassium thiocyanate to yield 4-thiocyanato-4-n-butyl-1,2-diphenyl-3,5-dioxopyrazolidine.

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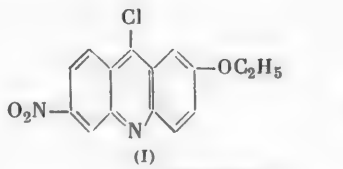
SYNTHESIS AND INVESTIGATION OF N-OXIDES OF HETEROCYCLIC COMPOUNDS

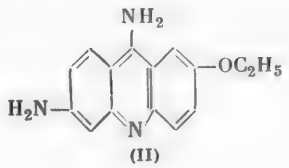
II. N-OXIDES OF ACRIDINE DERIVATIVES

A.M. Khaletskii, V.G. Pesin and Chou Ch'ing

In a preceding communication, data were presented from the synthesis and study of certain properties of the N-oxides of morphine, tetrahydroisoquinoline, and quinoline derivatives [1]. In the present paper, data are presented relating to the properties of some N-oxides of the acridine series. The interest in such compounds arises in connection with their importance in medicine and as intermediate products in synthesis; moreover, the oxidation of acridine derivatives has received comparatively little study. Thus, acridine N-oxides can be obtained by reduction of acridone N-oxides and by oxidation of acridine [2].

We studied the following acridine derivatives: 2-ethoxy-6-nitro-9-chloroacridine (I), 2-ethoxy-6,9-diaminoacridine (II), 2-ethoxy-6,9-di(acetylamino)acridine (III), 3,6-diaminoacridine (IV), and 3,6-di(acetylamino)acridine (V).


(I)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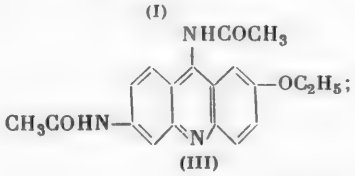
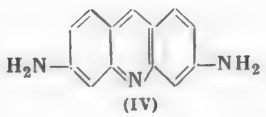

(III)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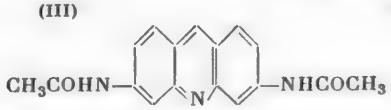
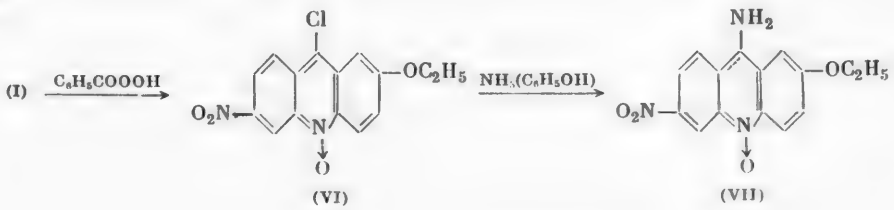
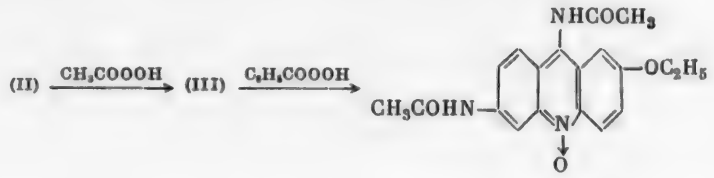

(V)

Oxidation of (I) with perbenzoic acid in chloroform gave an 89% yield of its N-oxide (VI), which, by interaction with gaseous ammonia (in phenol solution) was converted to the N-oxide of 2-ethoxy-6-nitro-9-aminoacridine (VII).


(VI) (VII)

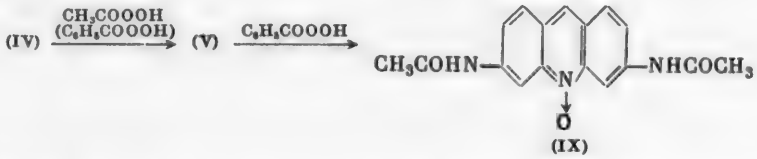
Thus, it was shown that the N-oxide group has no appreciable effect on the mobility of the chlorine; the chlorine in both (I) and (VI) readily enters into exchange reactions.

Upon oxidation of 2-ethoxy-6,9-diaminoacridine (II) with perbenzoic acid, no N-oxide was detected, and oxidation with peracetic acid (in the presence of acetic acid) and subsequent chromatization of the reaction products over aluminum oxide gave an 18.6% yield of 2-ethoxy-6,9-di(acetylamino)acridine (III); the latter was converted by oxidation with perbenzoic acid to the N-oxide of 2-ethoxy-6,9-di(acetylamino)acridine (VIII). Refluxing (VIII) with an aqueous-alcoholic solution of sodium hyposulfite gave (II).



(VIII)

3,6-Diaminoacridine (IV) behaved similarly with respect to peracetic and perbenzoic acids. Acylation occurred during the action of the latter acid on (IV), no N-oxide being detected under the conditions of the experiment. Oxidation of 3,6-di(acetylamino)acridine (V) with perbenzoic acid gave its N-oxide (IX).



(IX)

Thus, the peracids tested by us are not suitable for the direct conversion of aminoacridines to the corresponding N-oxides. When aminoacridines are oxidized with peracetic acid, acylation takes place first, and only then are the N-oxides of the corresponding acyl derivatives formed.

EXPERIMENTAL

N-Oxide of 2-ethoxy-6-nitro-9-chloroacridine (VI). To a solution of 1.6 g of 2-ethoxy-6-nitro-9-chloroacridine (I) in 400 ml of chloroform at 18-20° was added from a dropping funnel, with constant stirring, a chloroform solution (15 ml) of perbenzoic acid containing 1.065 g of the latter. After four hours, the solution was filtered, the chloroform was evaporated, and the red-colored residue was treated with a 5% solution of ammonia. The residue insoluble in the ammoniacal solution was filtered, washed with water, and dried at 50°; 1.5 g (89.28%) of material was obtained. After recrystallization from chloroform, bright-red crystals were obtained in the form of long needles with m.p. 204-206° (with decomp.).

Found %: C 56.51, 56.78; H 3.54, 3.56; N 9.13, 8.79. $C_{15}H_{11}O_4N_3Cl$. Calculated %: C 56.51; H 3.54; N 8.79.

N-Oxide of 2-ethoxy-6-nitro-9-aminoacridine (VII). 0.5 g of (VI) was dissolved in 1.25 g of molten phenol, and dry ammonia was passed into the solution at 100-105°; amination was continued until a thick mass was obtained. On treatment of the latter with alcohol, a dark-brown precipitate was formed which, after separation and washing with hot water, was dried at 60°; 0.35 g (74.2%) of material was obtained. Solution in alcohol and precipitation with water gave a dark-red powder which melted at 262-265° (with decomp.).

0.2542 g of the substance, after being dried at 120°, lost 0.0138 g, and 0.3562 g lost 0.0188 g, which corresponds to 5.43% H_2O.

Found %: C 56.40, 56.70; H 5.14, 4.73; N 13.00, 12.98. $C_{15}H_{13}O_4N_3 \cdot H_2O$. Calculated %: C 56.78; H 4.73; N 13.25.

Oxidation of 2-ethoxy-6,9-diaminoacridine (II) with perbenzoic acid. To an alcoholic solution of perbenzoic acid (7.5 g in 42 ml of alcohol), cooled to 10°, was gradually added, with stirring, 75 ml of an alcoholic

solution of (II) containing 9.8 g of the latter. The resulting precipitate was filtered, washed with sodium hydroxide solution, and dried at 100°; m.p. 113-118°. A mixed sample with known 2-ethoxy-6,9-diaminoacridine showed no melting point depression.

Oxidation of 2-ethoxy-6,9-diaminoacridine (II) with peracetic acid. 2 g of 2-ethoxy-6,9-diaminoacridine was dissolved in 2 ml of 98% acetic acid; the solution was diluted with 200 ml of water, and to this solution was gradually added, with continuous stirring, 13 ml of peracetic acid in acetic acid containing 0.78 g of peracetic acid. After the dark-red solution had been stirred for ten minutes, it was neutralized with 10% sodium hydroxide solution, and the resulting precipitate was filtered, washed with water, and dried; 1.95 g was obtained. An alcoholic solution of the precipitate was passed through an aluminum oxide column (activated by drying at 300° for three hours). After development with alcohol, three zones were observed on the aluminum oxide. The lower part was pale yellow, the middle was brown, and the upper was yellow-brown.

An alcoholic solution of the material contained in the lower part* of the column was evaporated to dryness at 60°, resulting in the formation of lustrous, yellowish-brown needles; the 0.5 g of material (after recrystallization from a 1:1 mixture of alcohol and ether) corresponded to a yield of 18.6% based on the 2-ethoxy-6,9-diaminoacridine; the material did not melt when heated to 270°.

Found %: C 59.95, 60.10; H 6.36, 6.52; N 12.00, 12.27. $C_{14}H_{19}O_3N_3 \cdot 1.5H_2O$. Calculated %: C 60.00; H 6.47; N 12.36.

On the basis of the analytical data, the substance was the acetic acid salt of 2-ethoxy-6,9-diaminoacridine. This compound was readily soluble in water, and neutralization of the solution with a 10% solution of sodium hydroxide caused separation of a yellow precipitate. A mixed sample with known 2-ethoxy-6,9-diaminoacridine showed no depression of the melting point.

An alcoholic solution of the material from the center of the column was evaporated, and the residue was dried at 60° to give a yellowish-brown material. 2-Ethoxy-6,9-diaminoacridine and its acetate were separated from the material.

Evaporation of an alcoholic solution of the material contained in the lower part* of the column left a red residue, which, after recrystallization from alcohol, decomposed without melting at 235°; it did not give a cherry-red color when acted on by sodium nitrite in the presence of hydrochloric acid, and its nature remains unclear.

2-Ethoxy-6,9-di(acetylamino)acridine (III). 20 g of 2-ethoxy-6,9-diaminoacridine was acylated with 16 g of acetic anhydride by heating to 100° until all amino groups were substituted with acetyl radicals (i.e., to a negative reaction with sodium nitrite). On dilution of the solution with 0.5 liter of water, 11.9 g of a yellow material separated, and an additional 9.5 g was recovered from the mother liquor; a total of 22.4 g (88.3%) of material was obtained, m.p. 290-292°. Recrystallization from a mixture of pyridine and water gave yellow needles with an m.p. of 296-297° (with decomp.), which were readily soluble in pyridine and less soluble in alcohol, benzene, chloroform, dichloroethane, and other organic solvents.

Found %: C 61.30, 60.94; H 6.35, 6.35; N 11.36, 11.26. $C_{19}H_{19}O_3N_3 \cdot 2H_2O$. Calculated %: C 61.13; H 6.16; N 11.26.

When dried at 120°, 0.6159 g and 0.4580 g of the substance lost, respectively, 0.0588 g and 0.0432 g, which corresponds to 2 moles of water.

Found, after saponification with 0.1 N alcoholic potassium hydroxide, %: CH_3COOH 31.1, 31.4. $C_{19}H_{19}O_3N_3 \cdot 2H_2O$. Calculated %: CH_3COOH 31.33.

When the 2-ethoxy-6,9-di(acetylamino)acridine was refluxed with concentrated sulfuric acid, an odor of ethyl acetate developed, and simultaneously a yellow precipitate, with an m.p. of 110°, separated. A mixed sample with known 2-ethoxy-6,9-diaminoacridine showed no depression of the melting point.

N-Oxide of 2-ethoxy-6,9-di(acetylamino)acridine (VIII). 1 g of 2-ethoxy-6,9-di-(acetylamino)acridine was dissolved in 300 ml of alcohol and 50 ml of chloroform, and to the solution was added, with constant stirring,

*There is an inconsistency here. Another paragraph refers to the lower part of the column, also. One of the two probably is meant to refer to the upper part of the column – Editor's note.

8 ml of a chloroform solution of perbenzoic acid containing 0.56 g of the latter. After three hours, the solvent was evaporated (in air), and, after the yellowish-brown residue had been washed with ether, 0.95 g (90.6%) of material was obtained, which, after recrystallization from alcohol, melted at 247-248° (with decomp.) and which was in the form of yellow needles.

When dried at 120°, 0.2402 g and 0.2282 g of the substance lost, respectively, 0.0173 g and 0.0165 g, which corresponds to 1.5 molecules of water.

Found %: C 59.81, 60.24; H 6.07, 6.05; N 11.40, 11.18. $C_{19}H_{19}O_4N_3 \cdot 1.5H_2O$. Calculated %: C 60.00; H 5.79; N 11.05.

Oxidation of 3,6-diaminoacridine with perbenzoic acid. 1 g of (IV) was dissolved in 100 ml of chloroform and 5 ml of alcohol, and to the solution, which was at 15°, was added 14 ml of a chloroform solution of perbenzoic acid which contained 0.84 g of perbenzoic acid. The brown precipitate was filtered, and neutralized with a 10% solution of sodium hydroxide. It melted at 264-267° after being washed with water and dried. A mixed sample with known 3,6-diaminoacridine showed no depression of the melting point.

Oxidation of 3,6-diaminoacridine with peracetic acid. 2 g of (IV) was dissolved in 2 ml of 98% acetic acid, and the solution was diluted with 250 ml of water and oxidized with 16 ml of an acetic acid solution of peracetic acid containing 0.96 g of the latter. On neutralization with a 10% solution of ammonia, a fine, dark-brown precipitate separated, which was filtered and dried. Similarly to the case of the oxidation of 2-ethoxy-6,9-diaminoacridine with peracetic acid, the residue was a mixture of products of the oxidation of 3,6-diaminoacridine.

3,6-Diacetylaminoacridine [3]. A mixture of 2 g of 3,6-diacetylaminoacridine, 200 ml of chloroform, 1000 ml of alcohol was subjected to oxidation with 1.2 g of perbenzoic acid (in chloroform). After four hours, the solvent was removed by evaporation, and the residue was washed with ether and dried at 100°; 1.9 g of material was obtained, m.p. 175-188°. Solution in alcohol and precipitation with water gave 0.2 g (9.16%) of a substance with an m.p. of 236° (with decomp.); this was a yellowish-brown powder, soluble in alcohol and insoluble in water.

Found %: C 60.28, 60.71; H 5.73, 5.59; N 12.56, 12.20. $C_{17}H_{15}O_2N_3 \cdot 1.5H_2O$. Calculated %: C 60.71; H 5.36; N 12.50.

When dried at 120°, 0.2318 g and 0.1946 g of the substance lost, respectively, 0.0182 g and 0.0146 g, which corresponds to 1.5 molecules of water.

SUMMARY

The behavior of oxidizing agents (peracetic and perbenzoic acids) toward certain acridine derivatives was investigated. It was found that, on oxidation with peracetic acid, 2-ethoxy-6,9-diamino- and 3,6-diaminoacridine are first acetylated, and then form the N-oxides; oxidation of 2-ethoxy-6-nitro-9-chloroacridine forms the N-oxide in the normal manner, and replacement of the chlorine at C_9 by an amino group is not hindered by the N-oxide group.

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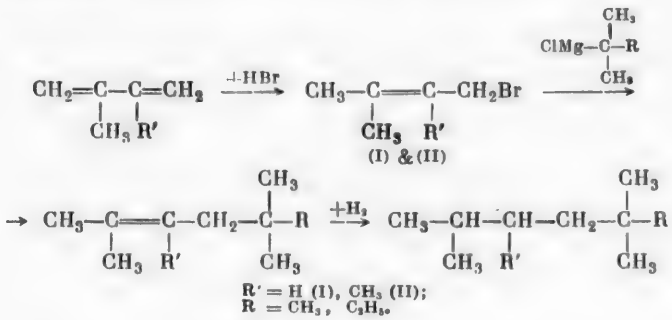
SYNTHESIS OF HYDROCARBONS

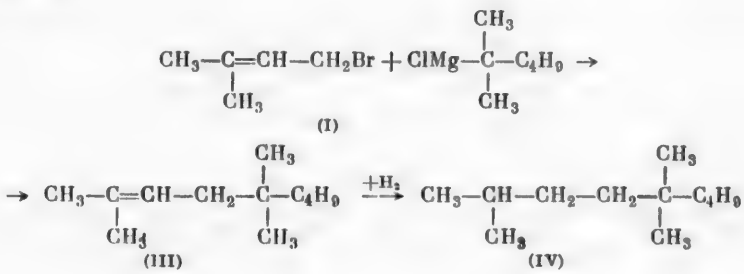
LXVII. C_{12} HYDROCARBONS WITH ONE AND TWO QUATERNARY CARBON ATOMS

R.Ia. Levina, P.A. Kaikaris and P.A. Gembitskii

A previous communication [1] described the synthesis of ethylenic (and from them, by hydrogenation – paraffinic) C_9-C_{11} hydrocarbons with single quaternary carbon atoms by the interaction of tert-alkylmagnesium chlorides (tert-butyl- and tert-amylmagnesium chlorides) with primary hydrohalides of isoprene [haloolefins] and 2,3-dimethyl-1,3-butadiene.

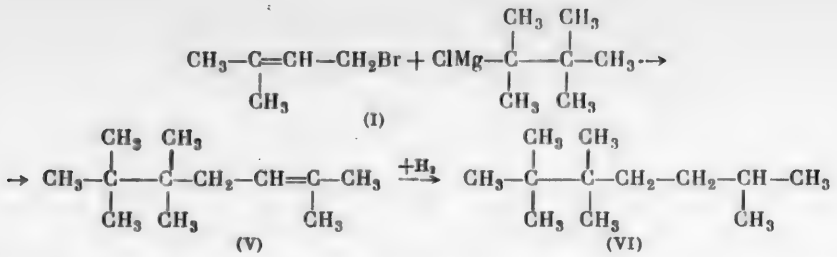


In the present work, the primary hydrobromide of isoprene [1-bromo-3-methyl-2-butene] (I) was used for the synthesis of ethylenic and paraffinic hydrocarbons having the composition $C_{12}H_{24}$ and $C_{12}H_{26}$. The interaction of isoprene hydrobromide with 2-chloromagnesium-2-methylhexane [2-methylhexylmagnesium bromide] gave an alkene with one quaternary carbon atom – 2,5,5-trimethyl-2-nonene (III), and hydrogenation of the alkene gave 2,5,5-trimethylnonane (IV).

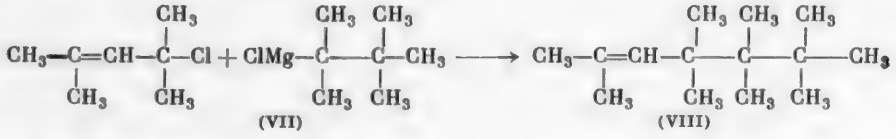


The reaction of isoprene hydrobromide with an organomagnesium compound isomeric with 2-chloro-2-methylhexane and having a more branched structure – 3-chloromagnesium-2,2,3-trimethylbutane [1,1,2,2-tetramethylpropylmagnesium chloride] (triptylmagnesium chloride*) – gave a $C_{12}H_{24}$ ethylenic hydrocarbon (V) with two adjacent quaternary carbon atoms – 2,2,3,3,6-pentamethyl-5-heptene – and hydrogenation of this compound gave 2,2,3,3,6-pentamethylheptane (VI).

*A.D. Petrov and co-workers[2] have described the synthesis of alkenes (in yields of 3 and 6.5%) by the interaction of triptyl chloride with magnesium and the simplest allylic chlorides – allyl and methallyl chloride. Similar reactions have also been described by these authors for other chlorides of the triptyl type.



These isomeric $C_{12}H_{24}$ alkenes and the isomeric $C_{12}H_{26}$ alkanes having one and two quaternary carbon atoms have not been described in the literature. The yields of both isomeric alkenes (III and V) were only 8 and 7%, calculated on the organomagnesium compound formed (the content of which in the ether solution was determined by titration). The low yields of alkenes is explained by the occurrence of numerous side processes which proceeded during the reactions between the diene hydrohalides and the tert-alkylmagnesium chlorides [3]. We made a further attempt to carry out the synthesis of a $C_{14}H_{28}$ hydrocarbon having three neighboring quaternary carbon atoms (VIII) by introducing triptylmagnesium chloride into a reaction with a tertiary allyl chloride – the hydrochloride of 2,4-dimethyl-1,3-pentadiene (VII).*



However, the attempt to synthesize a hydrocarbon of such highly branched structure (VIII) was unsuccessful, apparently owing to steric hindrance; distillation of the products of this reaction yielded only fractions corresponding in boiling points to C_7H_{12} and C_7H_{14} hydrocarbons and to the dimer of the first of these. A $C_{14}H_{28}$ hydrocarbon either was not formed at all, or it was formed in such small amount that it was not possible to separate it by distillation of the reaction products.

EXPERIMENTAL

The tertiary chlorides – 2-chloro-2-methylhexane and 3-chloro-2,2,3-trimethylbutane (triptyl chloride) – were prepared from the corresponding tertiary alcohols, 2-methyl-2-hexanol (b.p. 54-54.5° at 12 mm; literature value [5] 138-139° at 742 mm) and 2,2,3-trimethyl-3-butanol (triptanol) (m.p. 16°; literature value [6], m.p. 16°), by agitation with a two-fold amount of concentrated hydrochloric acid saturated at 0° with hydrogen chloride. The resulting chlorides (yield, 90%) were washed with water and dried. 2-Chloro-2-methylhexane: b.p. 36-37° at 14 mm, n_D^{20} 1.4212, d_4^{20} 0.8669. Literature data [5]: b.p. 127-128° at 753 mm, n_D^{20} 1.4193, d_4^{20} 0.8669. 3-Chloro-2,2,3-trimethylbutane: m.p. 130° (from methyl alcohol; in a sealed capillary). Literature data [6]: m.p. 128-134°.

Interaction of isoprene hydrobromide with 2-chloromagnesium-2-methylhexane. To 3 g-atoms of magnesium (preliminarily activated by heating with an iodine crystal) in 0.5 liter of absolute ether was slowly added a solution of 3 moles of the tertiary chloride – 2-chloro-2-methylhexane – in 1 liter of absolute ether. The resulting ethereal solution of organomagnesium compound was filtered in a stream of nitrogen from the unreacted magnesium (the content of organomagnesium compound in the ether solution, as determined by titration [7], was 56% of theoretical), the solution was cooled to −40°, and to it was added, with stirring, an ethereal solution (1 : 1) of primary isoprene hydrobromide [1] (1.7 mole; b.p. 58-62° at 56 mm; literature value [8]: b.p. 60-65° at 63 mm).

The reaction mixture was heated and stirred for several hours, and was decomposed by pouring onto a mixture of ice and acetic acid. After the usual treatment of the ether extracts and distillation of the ether and low-

*As we have shown previously [3, 4], the hydrochloride and hydrobromide of 2,4-dimethyl-1,3-pentadiene enter into a Grignard-Wurtz reaction with tert-alkylmagnesium chlorides (of less branched structure than triptylmagnesium chloride) forming hydrocarbons with two neighboring quaternary carbon atoms.

boiling (to 140°) fractions containing C_7H_{14} hydrocarbons and unreacted unsaturated tertiary chloride, the residue was distilled from polymers, refluxed over sodium to a negative reaction for halide, and distilled in a column. After two fractional distillations, 21 g of 2,5,5-trimethyl-2-nonene (8% calculated on the organomagnesium compound formed) was isolated; the nonene had the following constants:

B.p. 64.5-65° (4 mm), n_D^{20} 1.4421, d_4^{20} 0.7802; MR_D 57.10; calc. 57.15 (57.23*).

Found %: C 85.62, 85.73; H 14.42, 14.33. $C_{12}H_{24}$. Calculated %: C 85.63; H 14.37.

Interaction of isoprene hydrobromide with 3-chloromagnesium-2,2,3-trimethylbutane (triptylmagnesium chloride). The reaction was carried out by the method described above. The content of organomagnesium compound in the ether solution was 50%. Distillation of the reaction products gave a hydrocarbon fraction boiling at 150-200°, which was refluxed with sodium to the complete removal of halogen compounds and distilled over sodium in a column. Two fractional distillations gave 18 g of 2,2,3,3,6-pentamethyl-5-heptene (7% calculated on the organomagnesium compound formed) with the following constants:

B.p. 195.5° (750 mm), n_D^{20} 1.4493, d_4^{20} 0.7950, MR_D 56.82; calc. 57.15 (56.83).

Found %: C 85.62, 85.82; H 14.48, 14.41. $C_{12}H_{24}$. Calculated %: C 85.63; H 14.37.

Hydrogenation of both isomeric $C_{12}H_{24}$ alkenes was carried out over nickel on aluminum oxide at 170-180°. The resulting alkanes had the following constants after distillation in a column:

2,5,5-Trimethylnonane – b.p. 59° (5 mm), n_D^{20} 1.4236, d_4^{20} 0.7550; MR_D 57.50; calc. 57.62 (57.60).

Found %: C 84.60, 84.72; H 15.43, 15.33. $C_{12}H_{26}$. Calculated %: C 84.62; H 15.38.

2,2,3,3,6-Pentamethylheptane – b.p. 187.5-188° (745 mm), n_D^{20} 1.4345, d_4^{20} 0.7772, MR_D 57.15; calc. 57.62 (57.20).

Found %: C 84.68, 84.82; H 15.42, 15.19. $C_{12}H_{26}$. Calculated %: C 84.62; H 15.38.

The Raman spectra of these alkenes had lines at, respectively, 1664 cm^{-1} and 1668 cm^{-1}, which confirmed their structure as trisubstituted ethylenes. In the spectra of the alkanes, intense lines were present in the regions of 671, 926, and 1240 cm^{-1}, which are characteristic of highly branched hydrocarbon chains containing quaternary carbon atoms [10].

Interaction of the hydrochloride of 2,4-dimethyl-1,3-pentadiene (2-chloro-2,4-dimethyl-3-pentene) with triptylmagnesium chloride. The hydrochlorination of 2,4-dimethyl-1,3-pentadiene and the reaction of the resulting hydrochloride (1.7 moles) with triptylmagnesium chloride (from 3 moles of triptyl chloride and 3 g-atoms of magnesium) were carried out by the method described previously [3] (for the reaction between the same hydrochloride and other tert-alkylmagnesium chlorides). During the first distillation of the reaction products, fractions were collected which boiled in the ranges of 80-120° (containing C_7H_{12} and C_7H_{14} hydrocarbons), 120-180° (consisting mainly of unreacted triptyl chloride), and 215-250°. The fraction boiling at 215-250° was refluxed over sodium (to the complete removal of halogen), and was then distilled in a column to give 38 g (12%) of the dimer of 2,4-dimethyl-1,3-pentadiene [11] with a b.p. of 90° at 10 mm (218-220° at 760 mm) and n_D^{20} 1.4800; several grams of a higher-boiling fraction (90-105° at 10 mm, 220-235° at 760 mm) was also obtained, but this fraction was not investigated further.

SUMMARY

1. Previously undescribed $C_{12}H_{24}$ alkenes with one and two quaternary carbon atoms, 2,5,5-trimethyl-2-nonene and 2,2,3,3,6-pentamethyl-5-heptene, were synthesized by the interaction of isoprene hydrobromide with the tert-alkylmagnesium chlorides 2-chloromagnesium-2-methylhexane and 3-chloromagnesium-2,2,3-trimethylbutane (triptylmagnesium chloride).

2. Hydrogenation of these alkenes gave 2,5,5-trimethylnonane and 2,2,3,3,6-pentamethylheptane, which also have not been described previously.

*In parentheses (here and subsequently) is given MR_D calculated by the additive scheme of V.M. Tatevskii [9], which takes into account the subtypes of chemical bonds.

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**As in Russian. (Probably as yet unpublished.) See forthcoming C.B. translation.

INTERACTION OF γ-CHLOROPROPYLSILANE CHLORIDES WITH AROMATIC COMPOUNDS BY FRIEDEL-CRAFTS REACTION

E.A. Chernyshev, M.E. Dolgaia and Iu.P. Egorov

In preceding communications [1], we have described the interaction of various α- and β-chloroalkylsilane chlorides, obtained from methyl- and ethylchlorosilanes, with aromatic compounds in the presence of $AlCl_3$ or metallic aluminum. It was shown that β-chloroalkylsilane chlorides are considerably more active in this reaction than are α-chloroalkylsilane chlorides and also that aromatic compounds with the aromatic ring in the β-position are obtained quantitatively from α-chloroethyltrichlorosilane and partially from β-chloroethylethyldichlorosilane.

Continuing the investigation of the dependence of the reactivity of chloroalkylsilane chlorides on the position of the C–Cl bond relative to the silicon atom, in the present work we studied the interaction of β- and γ-chloropropyltrichlorosilanes and of β- and γ-chloropropylmethyldichlorosilanes with various aromatic compounds in the presence of $AlCl_3$ or of Al.

Both β-chloropropyltrichlorosilane and β-chloropropylmethyldichlorosilane react vigorously with benzene, toluene, and chlorobenzene to give the corresponding derivatives in yields of 40-60%. The reaction requires 10-15 hours at room temperature and 2-3 hours at 60-70°. In the case of diphenyl, diphenyl oxide, and naphthalene, only metallic aluminum was used as the catalyst in order to decrease tar formation. The yields of products in these cases were somewhat lower, but still comprised 20-40%. γ-Chloropropyltrichlorosilane and γ-chloropropylmethyldichlorosilane reacted just as vigorously as the corresponding β-isomers, and the yields of silicoalkylation products in this case, with few exceptions, were no lower.

Thus, even though the α-chloroalkylsilane chlorides have very low reactivity in comparison to the β-isomers, the reactivity of the γ-chloroalkylsilane chlorides is no less than the β-chlorides.

It might be expected that the γ-chlorides or the γ-carbonium ions, which are formed in the course of the reaction, would isomerize with the formation of the β-isomers. Precise fractionation showed that two substances corresponding to the β- and γ-isomers in a ratio of 1:2.9 actually are formed from γ-chloropropyltrichlorosilane and benzene. Only one substance is formed during the reaction of γ-chloropropylmethyldichlorosilane with benzene. All three compounds were methylated, and a comparison of their spectra showed that only the γ-isomer is formed in the second case.

$$Cl_3SiCH_2CH_2CH_2Cl + C_6H_6 \xrightarrow{AlCl_3} \begin{cases} \rightarrow Cl_3SiCH_2CHC_6H_5 \quad (16.2\%) \\ \qquad\qquad\quad | \\ \qquad\qquad\quad CH_3 \\ \rightarrow Cl_3SiCH_2CH_2CH_2C_6H_5 \quad (47\%) \end{cases}$$

$$CH_3SiCl_2CH_2CH_2CH_2Cl + C_6H_6 \xrightarrow{AlCl_3} Cl_3SiCH_2CH_2CH_2C_5H_6 \quad (34\%)$$

It is evident that γ-chloropropylmethyldichlorosilane is more reactive than γ-chloropropyltrichlorosilane in Friedel-Crafts reactions and that it enters into reactions with aromatic compounds without undergoing isomerization.

In order to establish the ratio of ortho-, meta-, and para-isomers in the silicoalkylation products of toluene, we carried out an analysis of the spectra (Raman spectra) of $(CH_3)_3SiCH_2CH_2CH_2C_6H_4CH_3$ and $(CH_3)_3SiCH_2CH(CH_3)$-$C_6H_4CH_3$. Since the spectra were identical, we present only the spectrum of the first substance:

TABLE 1

Silicoalkylating agent	Aromatic compound	Catalyst	Compound obtained	Reaction time (hours)	Yield (in %) based on original chloride	Boiling point (pressure in mm)
$Cl_3SiCHClCH_2CH_3$	C_6H_6	Al	$Cl_3SiC_3H_6C_6H_5$ Phenylpropyltrichlorosilane	2—3	18.0	100° (6)
			$[Cl_3SiC_3H_6]_2C_6H_4$ Bis(trichlorosilylpropyl)benzene	2—3	14.4	172—173 (6)
$Cl_3SiCH_2CHClCH_3$	C_6H_6	$AlCl_3$	$Cl_3SiCH_2CHC_6H_5$ (CH₃) β-Phenylpropyltrichlorosilane	22	53.25	101—102 (6)
$Cl_3SiCH_2CHClCH_3$	C_6H_5Cl	$AlCl_3$	$Cl_3SiCH_2CHC_6H_4C$ (CH₃) β-Chlorophenylpropyltrichlorosilane	8	58.0	135—136 (8.5)
$Cl_3SiCH_2CHClCH_3$	$C_6H_5CH_3$	$AlCl_3$	$Cl_3SiCH_2CHC_6H_4CH_3$ (CH_2) β-Tolylpropyltrichlorosilane	7—8	57.7	122.5 (9)
$Cl_3SiCH_2CHClCH_3$	$C_{12}H_{10}$	Al	$Cl_3SiCH_2CHC_{12}H_9$ (CH₃) β-Xenylpropyltrichlorosilane	5—6	22.8	188—189 (6.5)
$Cl_3SiCH_2CHClCH_3$	$C_{12}H_{10}O$	Al	$Cl_3SiCH_2CHC_{12}H_9O$ (CH₃) β-(p-Phenoxyphenyl)propyltrichlorosilane	1.5—2	42	183.5—185 (6)
$Cl_3SiCH_2CHClCH_3$	$C_{10}H_8$	Al	$Cl_3SiCH_2CHC_{10}H_7$ (CH₃) (β-Naphthyl)propyltrichlorosilane	1.5—2	29.4	172 (8)
$Cl_3SiCH_2CH_2CH_2Cl$	C_6H_6	$AlCl_3$	$Cl_3SiCH_2CHC_6H_5$ (CH₃) β-Phenylpropyltrichlorosilane	25—30	16.2	116—117 (10)
			$Cl_3SiCH_2CH_2CH_2C_6H_5$ γ-Phenylpropyltrichlorosilane	25—30	47.0	120 (10)
$Cl_3SiCH_2CH_2CH_2Cl$	C_6H_5Cl	$AlCl_3$	$Cl_3SiC_3H_6C_6H_4Cl$ Chlorophenylpropyltrichlorosilane	2—3	73	135 (5)
$Cl_3SiCH_2CH_2CH_2Cl$	$C_6H_5CH_3$	Al	$Cl_3SiC_3H_6C_6H_4CH_3$ Tolylpropyltrichlorosilane	2—3	34	126.5—127 (4)
$Cl_3SiCH_2CH_2CH_2Cl$	$C_{12}H_{10}$	Al	$Cl_3SiC_3H_6C_{12}H_9$ Xenylpropyltrichlorosilane	5—6	44.8	193—194 (6.5)

n_D^{20}	d_4^{20}	MR_D found	MR_D calc.	Found (in %) C	Found (in %) H	Found (in %) Si	Found (in %) Cl	Empirical formula	Calculated (in %) C	Calculated (in %) H	Calculated (in %) Si	Calculated (in %) Cl
1.5155	1.2301	62.16	62.67	42.42, 42.68	4.43, 4.54	10.69, 10.81	40.90, 41.01	$C_9H_{11}SiCl_3$	42.61	4.33	11.06	42.00
1.5200	1.3156	99.59	98.97	33.73, 33.81	3.83, 3.84	12.54, 12.27	48.67, 48.42	$C_{12}H_{18}Si_2Cl_6$	33.57	3.73	13.04	49.66
1.5155	1.2260	62.37	62.67	42.80, 42.72	4.69, 4.48	10.51, 10.75	40.93, 41.13	$C_9H_{11}SiCl_3$	42.62	4.37	11.06	41.95
1.5300	1.3189	67.42	67.51	37.96, 37.65	3.40, 3.28	10.40, 10.44	48.16, 48.60	$C_9H_{10}SiCl_4$	37.52	3.52	9.74	49.22
1.5190	1.2002	67.70	67.30	44.71, 44.76	4.93, 4.79	10.59, 10.27	38.99, 38.59	$C_{10}H_{13}SiCl_3$	44.97	4.89	10.46	39.68
1.5765	1.2342	88.37	86.91	54.84, 54.86	4.63, 4.36	8.37, 8.50	31.84, 31.52	$C_{15}H_{15}SiCl_3$	54.65	4.55	8.50	32.30
1.5562	1.2471	89.15	88.68	52.41, 52.62	4.37, 4.38	8.45, 7.90	30.33, 30.48	$C_{15}H_{15}OSiCl_3$	52.12	4.34	8.10	30.79
1.5812	1.2617	80.19	78.12	51.90, 51.73	4.61, 4.78	8.13, 9.14	33.65, 33.22	$C_{13}H_{13}SiCl_3$	51.45	4.28	9.23	35.04
1.5159	1.2260	62.93	62.67	42.74, 42.94	4.48, 4.61	11.10, 11.12	40.68, 40.63	$C_9H_{11}SiCl_3$	42.62	4.37	11.06	40.95
1.5150	1.2248	62.38	62.67	42.68, 42.78	4.47, 4.62	11.20, 11.15	40.54, 40.69	$C_9H_{11}SiCl_3$	42.62	4.37	11.06	40.95
1.5292	1.3140	67.57	67.51	37.92, 37.88	3.59, 3.56	9.43, 9.71	48.22, 48.04	$C_9H_{10}SiCl_4$	37.52	3.52	9.74	49.22
1.5145	1.1988	67.19	67.30	45.13, 45.10	5.15, 5.13	10.43, 10.77	39.48, 39.53	$C_{10}H_{13}SiCl_3$	44.97	4.89	10.46	39.68
1.5768	1.2313	88.61	86.91	54.69, 54.60	5.13, 4.91	7.40, 7.68	31.13, 31.53	$C_{15}H_{15}SiCl_3$	54.65	4.55	8.50	32.30

(continued)

TABLE 1 (continued)

Silicoalkylating agent	Aromatic compound	Catalyst	Compound obtained	Reaction time (hours)	Yield (in %) based on original chloride	Boiling point (pressure in mm)
$Cl_3SiCH_2CH_2CH_2Cl$	$C_{12}H_{10}O$	Al	$Cl_3SiC_3H_6C_{12}H_9O$ Phenoxyphenylpropyltrichlorosilane	5—6	48.3	196—197 (8)
$Cl_3SiCH_2CH_2CH_2Cl$	$C_{10}H_8$	Al	$Cl_3SiC_3H_6C_{10}H_7$ Naphthylpropyltrichlorosilane	2—3	6.3	172—174 (7.5)
$CH_3SiCl_2CH_2CHClCH_3$	C_6H_6	Al	$CH_3SiCl_2CH_2CHC_6H_5$ (CH$_3$) β-Phenylpropylmethyldichlorosilane	3—4	43.5	99 (6)
$CH_3SiCl_2CH_2CHClCH_3$	C_6H_5Cl	Al	$CH_3SiCl_2CH_2CHC_6H_4Cl$ (CH$_3$) β-Chlorophenylpropylmethyldichlorosilane	3—4	40.0	126—127 (6)
$CH_3SiCl_2CH_2CHClCH_3$	$C_6H_5CH_3$	Al	$CH_3SiCl_2CH_2CHC_6H_4CH_3$ (CH$_3$) β-Tolylpropylmethyldichlorosilane	3—4	40.0	111 (6)
$CH_3SiCl_2CH_2CHClCH_3$	$C_{12}H_{10}$	Al	$CH_3SiCl_2CH_2CHC_{12}H_9$ (CH$_3$) β-Xenylpropylmethyldichlorosilane	6—8	16	187—190 (6.5)
$CH_3SiCl_2CH_2CHClCH_3$	$C_{12}H_{10}O$	Al	$CH_3SiCl_2CH_2CHC_{12}H_9O$ (CH$_3$) β-(Phenoxyphenyl)-propylmethyldichlorosilane	6—8	26.6	180—184 (7)
$CH_3SiCl_2CH_2CHClCH_3$	$C_{10}H_8$	Al	$CH_3SiCl_2CH_2CHC_{10}H_7$ (CH$_3$) β-(Naphthyl)propylmethyldichlorosilane	2—3	26	171 (6)
$CH_3SiCl_2CH_2CH_2CH_2Cl$	C_6H_6	$AlCl_3$	$CH_3SiCl_2CH_2CH_2CH_2C_6H_5$ γ-Phenylpropylmethyldichlorosilane	8—10	34.0	114—115 (6)
$CH_3SiCl_2CH_2CH_2CH_2Cl$	C_6H_5Cl	Al	$CH_3SiCl_2CH_2CH_2CH_2C_6H_4Cl$ γ-Chlorophenylpropylmethyldichlorosilane	4—5	43.6	130—131 (6.5)
$CH_3SiCl_2CH_2CH_2CH_2Cl$	$C_6H_5CH_3$	Al	$CH_3SiCl_2CH_2CH_2CH_2C_6H_4CH_3$ γ-Tolylpropylmethyldichlorosilane	6—8	60.8	123—125 (7)
$CH_3SiCl_2CH_2CH_2CH_2Cl$	$C_{10}H_8$	Al	$CH_3SiCl_2CH_2CH_2CH_2C_{10}H_7$ γ-Naphthylpropylmethyldichlorosilane	3—4	38.5	184—185 (5)
$Cl_3SiCH_2CH_2Cl$	$Cl_3SiCH_2CH_2C_6H_5$	Al	$(Cl_3SiCH_2CH_2)_2C_6H_4$ Bis(trichlorosilylethyl)benzene	42	22.6	180—181 (8)

n_D^{20}	d_4^{20}	MR_D found	MR_D calc.	Found (in %) C	Found (in %) H	Found (in %) Si	Found (in %) Cl	Empirical formula	Calculated (in %) C	Calculated (in %) H	Calculated (in %) Si	Calculated (in %) Cl
1.5549	1.2380	89.43	88.68	52.54, 52.67	4.64, 4.59	7.63, 7.27	30.48, 30.22	$C_{16}H_{15}OSiCl_3$	52.12	4.34	8.10	30.79
1.5792	1.2539	80.42	78.12	51.74, 51.65	4.64, 4.68	8.41, 8.53	33.33, 33.83	$C_{13}H_{13}SiCl_3$	51.45	4.28	9.23	35.04
1.5100	1.1109	62.70	63.04	51.45, 51.64	6.19, 6.19	10.83, 11.05	29.13, 29.06	$C_{10}H_{14}SiCl_2$	51.50	6.01	12.02	30.47
1.5238	1.2083	67.68	67.88	44.75, 44.68	4.92, 4.92	10.40, 10.52	39.17, 39.52	$C_{10}H_{12}SiCl_3$	44.86	4.86	10.47	39.81
1.5100	1.0926	67.52	67.67	53.52, 53.63	6.86, 6.84	10.55, 10.42	27.98, 27.60	$C_{11}H_{14}SiCl_2$	53.44	6.48	11.34	28.74
1.5732	1.1249	90.27	87.28	62.32, 62.44	5.85, 5.87	8.55, 8.64	20.03, 20.11	$C_{16}H_{16}SiCl_2$	62.12	5.82	9.06	22.95
1.5508	1.1620	89.20	89.15	59.00, 59.25	5.80, 5.86	8.06, 7.68	20.98, 21.13	$C_{14}H_{16}OSiCl_2$	59.08	5.53	8.61	21.85
1.5755	1.1594	80.69	78.49	59.47, 59.50	5.52, 5.52	9.72, 9.72	24.69, 24.91	$C_{14}H_{16}SiCl_2$	59.35	5 65	9.90	25.09
1·5105	1.1093	62.86	63.04	51.68, 51.74	6.11, 6.05	11.97, 12.04	27.82, 28.26	$C_{10}H_{14}SiCl_2$	51.50	6.01	62.02	30.47
1.5248	1.2109	67.68	67.88	45.08, 44.96	4.81, 4.85	10.00, 10.03	38.70, 38.44	$C_{10}H_{12}SiCl_3$	44.86	4.86	10.47	39.81
1.5115	1.0942	67.46	67.67	53.28, 53.30	6.66, 6.69	11.02, 10.90	27.79, 27.75	$C_{11}H_{14}SiCl_2$	53.44	6.48	11.34	28.74
1.5749	1.1589	80.59	78.49	59.22, 59.31	6.09, 5.97	9.49, 9.37	24.47, 24.27	$C_{14}H_{16}SiCl_2$	59.36	5.65	9.90	25.09
1.5275	1.3668	89.71	90.19	29.99, 30.13	2.81, 2.74	13.81, 13.72	51.82, 51.60	$C_{10}H_{12}SiCl_3$	29.93	2.99	13.96	53.12

TABLE 2

Original compound	Compound obtained	Yield (in %)	Boiling point (pressure in mm)	n_D^{20}	d_4^{20}	MR_D found
$Cl_3SiCH(C_6H_5)CH_2CH_3$	$(C_2H_5)_3SiCH(C_6H_5)CH_2CH_3$ α-Phenylpropyltriethylsilane	46	117—118° (6.5)	1.4965	0.8959	76.37
$Cl_3SiCH_2CH(C_6H_4Cl)CH_3$	$(CH_3)_3SiCH_2CH(C_6H_4Cl)CH_3$ β-Chlorophenylpropyltrimethylsilane	60.2	103—104 (6)	1.5022	0.9778	68.24
$Cl_3SiCH_2CH(C_6H_5)CH_3$	$(CH_3)_3SiCH_2CHC_6H_5$ | CH_3 β-Phenylpropyltrimethylsilane	57.1	94 (13)	1.4872	0.8723	63.33
$Cl_3SiCH_2CH(C_6H_4CH_3)CH_3$	$(CH_3)_3SiCH_2CH(C_6H_4CH_3)CH_3$ β-Tolylpropyltrimethylsilane	71.6	94 (6)	1.4900	0.8751	68.06
$Cl_3SiCH_2CH(C_{12}H_9)CH_3$	$(CH_3)_3SiCH_2CH(C_{12}H_9)CH_3$ β-Xenylpropyltrimethylsilane	38.8	157—158 (6)	1.5540	0.9573	89.72
$Cl_3SiCH_2CH(C_{12}H_9O)CH_3$	$(CH_3)_3SiCH_2CH(C_{12}H_9O)CH_3$ β-(Phenoxyphenyl)propyltrimethylsilane	80	164—166 (6)	1.5355	0.9829	90.03
$Cl_3SiCH_2CH(C_{10}H_7)CH_3$	$(CH_3)_3SiCH_2CH(C_{10}H_7)CH_3$ β-(Naphthyl)propyltrimethylsilane	43.4	147—148 (7)	1.5560	0.9553	81.09
$Cl_3SiCH_2CH_2CH_2C_6H_5$	$(CH_3)_3SiCH_2CH_2CH_2C_6H_5$ γ-Phenylpropyltrimethylsilane	55.9	84.5—85 (5)	1.4864	0.8701	63.40
$Cl_3SiCH_2CH_2CH_2C_6H_4Cl$	$(CH_3)_3SiCH_2CH_2CH_2C_6H_4Cl$ γ-Chlorophenylpropyltrimethylsilane	44.1	111—112 (8)	1.5021	0.9750	68.55
$Cl_3SiCH_2CH_2CH_2C_6H_4CH_3$	$(CH_3)_3SiCH_2CH_2CH_2C_6H_4CH_3$ γ-Tolylpropyltrimethylsilane	32.6	112—113 (10)	1.4885	0.8682	68.42
$Cl_3SiCH_2CH_2CH_2C_{12}H_9$	$(CH_3)_3SiCH_2CH_2CH_2C_{12}H_9$ γ-Xenylpropyltrimethylsilane	52.6	171 (6.5)	1.5529	0.9587	89.44
$Cl_3SiCH_2CH_2CH_2C_{12}H_9O$	$(CH_3)_3SiCH_2CH_2CH_2C_{12}H_9O$ γ-(Phenoxyphenyl)propyltrimethylsilane	50	163—164 (6)	1.5340	0.9817	89.92
$Cl_3SiCH_2CH_2CH_2C_{10}H_7$	$(C_2H_5)_3SiCH_2CH_2CH_2C_{10}H_7$ γ-Naphthylpropyltriethylsilane	56	188—190 (6)	1.5485	0.9585	94.08
$CH_3SiCl_2CH_2CH(C_6H_5)CH_3$	$(CH_3)_3SiCH_2CH(C_6H_5)CH_3$ β-Phenylpropyltrimethylsilane	80	79 (6.5)	1.4874	0.8717	63.39
$CH_3SiCl_2CH_2CH(C_6H_4Cl)CH_3$	$(CH_3)_3SiCH_2CH(C_6H_4Cl)CH_3$ β-Chlorophenylpropyltrimethylsilane	42	105 (7)	1.5050	0.9845	68.09
$CH_3SiCl_2CH_2CH(C_6H_4CH_3)CH_3$	$(CH_3)_3SiCH_2CH(C_6H_4CH_3)CH_3$ β-Tolylpropyltrimethylsilane	43.7	92—93 (6)	1.4898	0.8722	68.28
$CH_3SiCl_2CH_2CH(C_{12}H_9O)CH_3$	$(CH_3)_3SiCH_2CH(C_{12}H_9O)CH_3$ β-(Phenoxyphenyl)propyltrimethylsilane	65.8	164—165 (6)	1.5358	0.9868	89.72
$CH_3SiCl_2CH_2CH(C_{10}H_7)CH_3$	$(CH_3)_3SiCH_2CH(C_{10}H_7)CH_3$ β-(Naphthyl)propyltrimethylsilane	61.7	150 (6)	1.5558	0.9541	81.52
$CH_3SiCl_2CH_2CH_2CH_2C_6H_5$	$(CH_3)_3SiCH_2CH_2CH_2C_6H_5$ γ-Phenylpropyltrimethylsilane	87	78 (6.5)	1.4865	0.8664	63.68
$CH_3SiCl_2CH_2CH_2CH_2C_6H_4Cl$	$(CH_3)_3SiCH_2CH_2CH_2C_6H_4Cl$ γ-Chlorophenylpropyltrimethylsilane	72	110 (7.5)	1.5030	0.9760	68.45
$CH_3SiCl_2CH_2CH_2CH_2C_6H_4CH_3$	$(CH_3)_3SiCH_2CH_2CH_2C_6H_4CH_3$ γ-Tolylpropyltrimethylsilane	66	103—104 (7)	1.4900	0.8711	68.31
$CH_3SiCl_2CH_2CH_2CH_2C_{10}H_7$	$(CH_3)_3SiCH_2CH_2CH_2C_{10}H_7$ γ-Naphthylpropyltrimethylsilane	45	158—159 (6.5)	1.5535	0.9527	81.32

MR_D	Found (in %)				Empirical formula	Calculated (in %)			
calc.	C	H	Si	Cl		C	H	Si	Cl
76.67	77.09, 77.04	11.5, 11.33	10.94, 10.95	—	$C_{18}H_{28}Si$	76.93	11.11	11.96	—
68.62	63.49, 63.34	8.53, 8.59	11.38, 11.62	14.92, 15.32	$C_{12}H_{19}SiCl$	63.57	8.39	12.36	15.68
63.78	74.96, 74.92	10.57, 10.54	14.53, 14.27		$C_{12}H_{2}Si$	75.19	10.33	14.48	
68.35	75.90, 75.92	10.20, 10.00	12.81, 12.90		$C_{13}H_{22}Si$	75.92	10.27	13.81	
88.02	80.40, 80.40	8.93, 8.91	10.70, 10.50		$C_{18}H_{24}Si$	80.62	8.95	10.44	
89.79	76.20, 76.10	8.88, 8.71	9.35, 9.66		$C_{18}H_{24}OSi$	76.05	8.45	9.85	
79.23	79.22, 79.20	9.77, 9.89	9.95, 10.20		$C_{16}H_{22}Si$	79.34	9.09	11.57	
63.78	75.00, 75.20	10.78, 10.84	14.15, 14.42		$C_{12}H_{20}Si$	75.19	10.33	14.48	
68.62	63.46, 63.49	8.78, 8.60	12.38, 12.32	14.77, 14.96	$C_{12}H_{19}SiCl$	63.57	8.39	12.36	15.68
68.35	75.88, 75.70	10.23, 10.27	13.18, 13.58		$C_{13}H_{22}Si$	75.92	10.27	13.81	
88.02	80.82, 81.00	8.98, 8.92	9.24, 9.50		$C_{18}H_{24}Si$	80.61	8.95	10.44	
89.79	76.20, 76.20	8.44, 8.48	9.94, 9.45		$C_{18}H_{24}OSi$	76.05	8.45	9.85	
93.12	—	—	—	—	$C_{19}H_{28}Si$	—	—	—	—
63.78	—	—	—	—	$C_{12}H_{20}Si$	—	—	—	—
68.62	—	—	—	—	$C_{12}H_{19}SiCl$	—	—	—	—
68.35	—	—	—	—	$C_{13}H_{22}Si$	—	—	—	—
89.79	—	—	—	—	$C_{18}H_{24}OSi$	—	—	—	—
79.23	79.30, 79.50	9.13, 9.34	11.32, 11.00		$C_{16}H_{22}Si$	79.34	9.09	11.57	
63.78	—	—	—	—	$C_{12}H_{20}Si$	—	—	—	—
68.62	—	—	—	—	$C_{12}H_{19}SiCl$	—	—	—	—
68.35	—	—	—	—	$C_{13}H_{22}Si$	—	—	—	—
79.23	79.65, 79.70	9.38, 9.26	11.28, 11.33		$C_{16}H_{22}Si$	79.34	9.09	11.57	

224 (4b), 407 (0), 425 (1), 522 (1b), 550 (1b), 588 (2), 609 (8), 644 (4), 694 (4b), 728 (3b), 773 (0), 810 (3), 824 (3), 900 (1), 1000 (7), 1050 (3b), 1081 (3b), 1181 (5b), 1209 (4), 1243 (3), 1277 (2), 1309 (3), 1378 (4), 1407 (3b), 1451 (3b), 1611 (5 db b).

On the basis of the work of Landsberg et al. [2], it is possible to assign the frequencies at 444, 648, 806, 824, 1182, and 1378 cm^{-1} to the para-isomer, the frequencies at 520, 751, 1005, and 1242 cm^{-1} to the meta-isomer, and the frequencies at 758, 1052, and 1226 cm^{-1} to the ortho-isomer. By comparing the intensities of these lines, it was possible to conclude that the para-isomer comprised 50%, the meta-isomer 40%, and the ortho-isomer 10% of the mixture. Approximately the same ratios were also obtained for the products of the silicoalkylation of chlorobenzene.

During the silicoalkylation of benzene with α-chloropropyltrichlorosilane, there was also formed, along with the mono-substituted benzene (18%, evidently a mixture of the α- and β-isomers), disilicoalkylated benzene in a yield of 14.4%. Silicoalkylation of β-phenylethyltrichlorosilane with β-chloroethyltrichlorosilane led to bis-β-(trichlorosilyl)benzene in 32.6% yield. The majority of the substances prepared were methylated by means of CH_3MgCl.

EXPERIMENTAL

The α-, β-, and γ-chloropropyltrichlorosilanes were prepared by the method of [3].

Chlorination of methylpropyldichlorosilane. The reaction was carried out in an apparatus which has previously been described [4]. 1000 g of methylpropyldichlorosilane was taken for the reaction. The reaction was carried out by heating to a temperature of 160° in a flask. Chlorine was passed into the reaction mixture at a rate of 200 bubbles per minute (through a standard Tishchenko flask). Distillation in a column of 30 theoretical plates gave 337 g of methylpropyldichlorosilane, b.p. 124° (760 mm), n_D^{20} 1.4240, d_4^{20} 1.0423; 142.7 g (17.7%) of α-chloropropylmethyldichlorosilane, b.p. 153° (760 mm), n_D^{20} 1.4518, d_4^{20} 1.1822; 3078 (38.1%) β-chloropropylmethyldichlorosilane, b.p. 160° (760 mm), 55° (15 mm), n_D^{20} 1.4538, d_4^{20} 1.1945; 263.5 g (32.7%) of γ-chloropropylmethyldichlorosilane, n_D^{20} 1.4610, d_4^{20} 1.2267. The yields are based on the methylpropyldichlorosilane reacted.

β-Phenylpropyltrichlorosilane. The reaction of β-chloropropyltrichlorosilane with benzene was carried out in a three-necked flask fitted with a stirrer, a thermometer, a reflux condenser, and a dropping funnel. 78 g of benzene and 1.0 g of $AlCl_3$ were placed in the flask. 42.36 g (0.2 mole) of β-chloropropyltrichlorosilane was gradually introduced dropwise and with vigorous stirring. The reaction, with copious evolution of HCl, began immediately on the addition of the silane chloride. After all of the chloride had been added, the reaction mixture was heated at 80° for a period of 20 hours. 2 g of $POCl_3$ was then added, the precipitate was filtered, and the filtrate was distilled. 27 g (53.25%) of β-phenylpropyltrichlorosilane was obtained; b.p. 101-102° (6 mm). The reactions of β-chloropropyltrichlorosilane with toluene and with chlorobenzene were carried out under similar conditions; the results are presented in Table 1.

β-Xenylpropyltrichlorosilane. The reaction of β-chloropropyltrichlorosilane with diphenyl was carried out in a three-necked flask fitted with a reflux condenser, a stirrer, a dropping funnel, and a thermometer. 53.9 g of diphenyl and 0.2 g of metallic aluminum were placed in the flask. At a reaction temperature of 80°, after the diphenyl had melted, 42.36 g (0.2 mole) of β-chloropropyltrichlorosilane was gradually added with vigorous stirring. Vigorous evolution of HCl began at 90° and continued during the addition of all of the chloride. The reaction mixture was then heated for 2-3 hours at 90-100°. Distillation isolated 15 g (22.8%) of β-xenylpropyltrichlorosilane; b.p. 188-189° (6.5 mm).

All of the remaining reactions with α-, β- and γ-chloropropyltrichlorosilanes and with α-, β-, and γ-chloropropylmethyldichlorosilanes were carried out under analogous conditions. The results are presented in Table 1.

All of the substances prepared were methylated, and the results are presented in Table 2.

SUMMARY

1. The interaction of β- and γ-chloropropylsilane chlorides with aromatic compounds was studied in the presence of $AlCl_3$ or Al. It was shown that the reactivity of the γ-chloroalkylsilane chlorides in this reaction is

no lower than the reactivity of the corresponding β-isomers.

2. Silicoalkylation of benzene with γ-chloropropyltrichlorosilane gave the β- and γ-isomers in a ratio of 1:2.9. Silicoalkylation of benzene with γ-chloropropylmethyldichlorosilane gave only the γ-isomer.

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SYNTHESIS OF β-CHLOROETHYL PHENYL ACETAL

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In previous work [1], the interaction of vinyl alkyl ethers with ethylene chlorohydrin was investigated, and some of the chemical properties of the resulting β-chloroethyl alkyl acetals were studied. In the present work, reactions in which ethylene chlorohydrin adds to vinyl aryl ethers were investigated using vinyl phenyl ether as an example of such ethers:

$$CH_2{=}CHOC_6H_5 + ClCH_2CH_2OH \rightarrow CH_3CH\begin{matrix}OC_6H_5\\OCH_2CH_2Cl\end{matrix}$$

The study of this reaction showed that, along with the reaction forming acetaldehyde β-chloroethyl phenyl acetal, disproportionation of this product to acetaldehyde diphenyl acetal and di(β-chloroethyl) acetal also proceeds according to:

$$2CH_3CH\begin{matrix}OC_6H_5\\OCH_2CH_2Cl\end{matrix} \rightarrow CH_3CH(OC_6H_5)_2 + CH_3CH(OCH_2CH_2Cl)_2$$

An analogous occurrence has previously been observed during a study of β-chloroethyl alkyl acetals [1].

EXPERIMENTAL

20.13 g of ethylene chlorohydrin (b.p. 129°, n_D^{20} 1.4412) was placed in a three-necked flask fitted with a reflux condenser, a mechanical stirrer, and a thermometer. 30.03 g of vinyl phenyl ether (b.p. 155°, n_D^{20} 1.5232) was gradually added, with stirring, to the flask. No signs of reaction were observed during the addition. One drop of concentrated hydrochloric acid was then added, and the mixture was heated to 145° over a period of five hours. The reaction mixture was dried over potassium carbonate and distilled under vacuum. The following fractions were collected:

First fraction, to 83° (5 mm), n_D^{20} 1.4950, 1.92 g; second fraction, 84-116° (4 mm), n_D^{20} 1.4668, 18.58 g; third fraction, 117-139° (4 mm), n_D^{20} 1.5382, 23.12 g; kettle residue, 4.0 g.

The first fraction and the kettle residue were not investigated further.

A second distillation of the second fraction isolated 11.0 g (47%) of acetaldehyde di(β-chloroethyl) acetal with a b.p. of 93-95° (6 mm), n_D^{20} 1.4548, d_4^{20} 1.1796.

Investigation of the third fraction showed that it contained 9.74 g (36%) of acetaldehyde diphenyl acetal [2] with a b.p. of 162° (10 mm), n_D^{20} 1.5587, d_4^{20} 1.0937, MR_D 63.13, calc. 62.94, and 4.07 g (8.1%) of acetaldehyde β-chloroethyl phenyl acetal (a colorless liquid, soluble in organic solvents and insoluble in water), b.p. 127-130° (8 mm), n_D^{20} 1.5108, d_4^{20} 1.1318, MR_D 53.10, calc. 52.93.

Found %: C 60.06, 59.82; H 6.76, 6.90; Cl 17.62, 17.56. $C_{10}H_{13}O_2Cl$. Calculated %: C 59.85; H 6.53; Cl 17.66.

SUMMARY

1. The interaction of vinyl phenyl ether with ethylene chlorohydrin was investigated, and acetaldehyde β-chloroethyl phenyl acetal was characterized for the first time.

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SYNTHESIS OF γ,γ'-DIPHENYLDIPROPYL ACETAL

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A method was previously proposed by one of us [1] for the preparation of acetals of the most varied structure, and some of the chemical properties of these compounds were studied. The purpose of the present work was the study of the interaction of acetaldehyde di(β-chloroethyl) acetal with a Grignard reagent. Considering that acetaldehyde di(β-chloroethyl) acetal is simultaneously a representative of both acetals and halogen compounds, it would be expected that it could react either as an alkyl halide or at the C—O bond by a Chichibabin-Elgazin reaction [2].

Summing up the investigation of this reaction, which was studied using the interaction of benzylmagnesium chloride with acetaldehyde di(β-chloroethyl)acetal, it was shown that the reaction proceeds through the chlorine atoms according to the scheme:

$$CH_3CH(OCH_2CH_2Cl)_2 + 2C_6H_5CH_2MgCl \rightarrow CH_3CH(OCH_2CH_2CH_2C_6H_5)_2,$$

while in our previous investigations [3], it was found that the interaction of a Grignard reagent with symmetrical and with mixed acetals not containing halogen in the alcohol radicals proceeds at the C—O bonds.

EXPERIMENTAL

To the Grignard reagent, prepared from 8 g of magnesium and 42 g of benzyl chloride, was gradually added 23 g of acetaldehyde di(β-chloroethyl) acetal [4]. When the resulting viscous reaction mixture was further heated, it unexpectedly foamed and then solidified. After the mass was cooled, it was treated with 5% acetic acid until it had completely dissolved. The ether layer was separated, washed with water, dried over sodium sulfate, and placed in a distillation flask. The ether was distilled, and the residue (19.8 g) was distilled under vacuum. The following fractions were obtained: 1st fraction, 75-120° (11 mm), 2.05 g; 2nd fraction, 121-181° (11 mm), 5.67 g; 3rd fraction, 182-260° (10 mm), 2.9 g; kettle product, 2.9 g (dibenzyl). The first and third fractions were not investigated. During the investigation of the 2nd fraction, 3.09 g (8.4%) of acetaldehyde di(γ-phenylpropyl) acetal was isolated. It was a colorless liquid with an aromatic odor, readily soluble in organic solvents and insoluble in water.

B.p. 111° (6 mm), n_D^{20} 1.5288, d_4^{20} 1.0073, MR_D 90.64; calc. 91.24.

Found %: C 80.26, 80.52; H 8.60, 8.75. $C_{20}H_{26}O_2$. Calculated %: C 80.53; H 8.72.

SUMMARY

The interaction of acetaldehyde di(β-chloroethyl) acetal with benzylmagnesium chloride was investigated. It was established that the reaction proceeds through the chlorine atoms, and not at the C—O bonds. Acetaldehyde di(γ-phenylpropyl) acetal was described for the first time.

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INVESTIGATIONS IN THE FIELD OF THE SYNTHESIS AND CONVERSIONS OF OXYGEN-CONTAINING ORGANOSILICON COMPOUNDS

ON THE INTERACTION OF VINYLALKYLCHLOROSILANES WITH VINYL BUTYL ETHER AND VINYL LACTAMS

M.F. Shostakovskii, D.A. Kochkin, V.A. Neterman and F.P. Sidel'kovskaia

It is known from the literature that vinylalkylchlorosilanes do not polymerize even when heated in the presence of either peroxides [1] or ionic [2] catalysts, or else they form polymers of comparatively low molecular weight. It appeared to be of interest to investigate whether polymerization or copolymerization of these compounds with other unsaturated compounds is possible. We established that vinylalkyldihalosilanes, for example, vinylethyldichloro- and vinyltrichlorosilane, do not polymerize on long heating (100°, 200 hours) in the presence of either ionic ($SnCl_2$, $SnCl_4$, BF_3) or free radical (triethylaluminum, azobisisobutyronitrile) initiators. At the same time, unsaturated organosilicon compounds containing a double bond in the middle of the silicon-carbon chain or containing two conjugated double bonds have a tendency toward polymerization, either under the influence of radical initiators or through the action of light. Thus, for example, tetrachlorodiethylsilylbutene [3], $C_2H_5SiCl_2CH_2CH_2CH=CHSiCl_2C_2H_5$ has been polymerized to a solid, alcohol- and ether-insoluble polymer by heating at 100° for 80 hours in the presence of azobisisobutyronitrile. The action of light over a period of five months converted ethyldichlorobutadienylsilane to a transparent, rubbery mass.

The following pairs of monomers were investigated in the study of the copolymerization of vinylalkylchlorosilanes: vinylmethyl- and vinylethyldichlorosilanes with vinyl butyl ether, vinylcaprolactam, and vinylpyrrolidone. The experiments were carried out at room temperature and at 60° and both with and without azobisisobutyronitrile present. It was found that under these conditions, vinylalkylchlorosilanes neither polymerize nor copolymerize. They are initiators of the polymerization of vinyl butyl ether, vinylcaprolactam, and vinylpyrrolidone.

However, in the case of the interaction of vinylalkyldichlorosilanes with vinylpyrrolidone, in addition to vinylpyrrolidone polymer, there was obtained a small amount of products containing silicon and nitrogen in the molecule; these were apparently produced by the interaction of these monomers. The initiation of polymerization by vinylalkylhalosilanes was probably due to the liberation of hydrogen chloride, which causes ionic polymerization of unsaturated compounds. For comparison, experiments were carried out on the polymerization of vinyl butyl ether, vinylcaprolactam, and vinylpyrrolidone in the presence of a saturated alkylhalosilane, namely, ethyltrichlorosilane, which also readily liberates hydrogen chloride. In this case also, polymerization of the indicated unsaturated compounds was observed, which indicates that the alkylhalosilane and the vinylalkylhalosilanes behave analogously. Thus, vinylalkyl- and alkylhalosilanes can be used as polymerization initiators.

EXPERIMENTAL

The vinylmethyl- and vinylethyldichlorosilanes were prepared by the previously described [3] vinylation of methyl- and ethyldichlorosilanes. The vinylcaprolactam and vinylpyrrolidone were synthesized by vinylation of caprolactam and pyrrolidone.

All polymerization experiments were carried out in sealed tubes into which were introduced the calculated amounts of the monomers (total amount was 5 g; 0.2% initiator); the tubes were sealed, and then were heated at

60° for 72 hours in some cases, and were allowed to stand at room temperature for several days in other cases. The polymeric products obtained from vinyl butyl ether and vinylalkyldichlorosilane were freed from unreacted monomers by treatment with ethyl alcohol, and were then vacuum dried to constant weight. Molecular weights of the polymers were determined cryoscopically. Molecular weights of 5770 and 5200 were found for the products from Experiments 1 and 2, respectively.

The polymers formed during the reactions of vinylpyrrolidone and vinylcaprolactam with the vinylalkyldichlorosilanes were precipitated from benzene solution with ether, dried under vacuum to constant weight, and analyzed for content of C, H, Si, N, and Cl. During the reaction of vinylpyrrolidone and of vinylcaprolactam with vinylethyldichlorosilane at 60°, tarry, heterogeneous, dark masses were formed, the separation of which was difficult.

The products from the reaction of vinylpyrrolidone and vinylmethyldichlorosilane, both with and without azobisisobutyronitrile present, contained silicon. In order to fractionate these polymers, they were treated with ethyl alcohol. This treatment gave small amounts of alcohol-insoluble powders (0.3%), which were apparently products of the interaction of vinylmethyldichlorosilane and vinylpyrrolidone.

Composition of the powder obtained from the experiment using an initiator, %: C 30.00, 29.91; H 5.98, 5.94; Cl 0.26, 0.30; Si 33.20, 33.53; N 1.68, 1.78. Composition of the powder from the experiment without an initiator, %: C 27.47, 27.04; H 5.78, 5.59; Cl – none; Si 32.90, 33.63; N 4.29, 4.02.

SUMMARY

1. The interaction of vinylalkyl- and alkylhalosilanes with vinyl butyl ether, vinylcaprolactam, and vinylpyrrolidone was investigated.

2. The monomer pairs studied formed practically no copolymers.

3. The major products of the interaction of the indicated compounds were polymers of vinyl butyl ether, vinylcaprolactam, and vinylpyrrolidone.

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SYNTHESIS OF ALKENYL-α-CN-ISOPROPOXYSILANES

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Alkyl- and aryl-α-CN-isopropoxysilanes have been investigated in a number of researches [1-3]. The interest in these compounds is explained, on the one hand, by the ease of introduction of a CN-containing radical into the molecule of an organosilicon compound, and, on the other hand, by the tendency of the Si–O bond, which is screened by a branch radical, toward hydrolysis [2, 3]. In a previous paper [2], we reported on the synthesis of a polymeric CN-containing product by hydrolysis of $C_2H_5SiCl_2[OC(CH_3)_2CN]$. The aim of the present investigation was the synthesis of α-CN-isopropoxysilanes containing unsaturated radicals, which are also needed for the production of CN-containing organosilicon polymers. Both alkenyl-α-CN-isopropoxysilanes [4] and alkenyl-α-CN-isopropoxysilanes containing hydrogen attached to the silicon [5, 6] were of interest. The original alkenylchlorosilanes, both with and without an Si–H bond, were prepared by direct synthesis [7, 8] and also by photochemical chlorination and dehydrochlorination of ethyltrichlorosilane [9].

These chlorosilanes were converted to the corresponding α-CN-isopropoxylsilyl derivatives by interaction with acetone cyanohydrin:

$$R_mSiCl_n + n \cdot HOC(CH_3)_2CN \xrightarrow{nC_5H_5N} R_mSi[OC(CH_3)_2CN]_n + nC_5H_5N \cdot HCl,$$

where $m = 1$ or 2, $m + n = 4$, a R = $CH_2{=}CH{-}CH_2$, $CH_2{=}C(CH_3){-}CH_2$ and $CH_2{=}CH$.

However, the interaction of allyl- and methallyldichlorosilanes with acetone cyanohydrin and pyridine, with the latter two in excess over the calculated amounts, unexpectedly gave alkenyltri-α-CN-isopropoxysilanes, in addition to the expected alkenyl-di-α-CN-isopropoxysilanes containing an Si–H group. In a control experiment, the interaction of $CH_2{=}C(CH_3){-}CH_2{-}SiH[OC(CH_3)_2CN]_2$ with acetone cyanohydrin and pyridine* also gave $CH_2{=}C(CH_3){-}CH_2{-}Si[OC(CH_3)_2CN]_3$. Similarly, from CH_3SiCl_2H was obtained $CH_3Si[OC(CH_3)_2CN]_3$ according to the equation:

$$CH_3SiCl_2H + 4HOC(CH_3)_2CN \xrightarrow{4C_5H_5N} CH_3Si[OC(CH_3)_2CN]_3 + 2C_5H_5N \cdot HCl + H_2 + 2C_5H_5N + HOC(CH_3)_2CN.$$

It is curious that other tertiary alcohols react with Si–H-containing silanes only under rigorous conditions – heating in an autoclave in the presence of alkali [10]. The ease with which acetone cyanohydrin reacts both with Si–H and with Si–Cl [1-3] may obviously be explained by the activating effect of the polar CN group on the hydroxyl of the alcohol.

*The use of pyridine as a catalyst for reactions between Si–H-containing silanes and acetone cyanohydrin is the most interesting, because mineral bases are not applicable in the case of acetone cyanohydrin, since they cleave cyanohydrins with the formation of ketones and hydrochloric acid.

We also studied the feasibility of introducing an allyloxy radical into the molecule of alkyl-α-CN-isopropoxychlorosilanes by the reaction:

$$(CH_3)_2Si[OC(CH_3)_2CN]Cl + HOCH_2{-}CH{=}CH_2 \xrightarrow{C_5H_5N} \rightarrow (CH_3)_2Si(OCH_2{-}CH{=}CH_2)[OC(CH_3)_2CN] + C_5H_5N \cdot HCl,$$

and in this case, along with the product expected from the above equation, $(CH_3)_2Si(OCH_2{-}CH{=}CH_2)_2$ and $(CH_3)_2Si[OC(CH_3)_2CN]_2$ were also obtained. The formation of these latter two compounds is explained by transesterification:

$$(CH_3)_2Si(OCH_2{-}CH{=}CH_2)[OC(CH_3)_2CN] \rightleftarrows (CH_3)_2Si(OCH_2CH{=}CH_2)_2 + + (CH_3)_2Si[OC(CH_3)_2CN]_2$$

or by disproportionation of the allyloxy and α-cyanoisopropoxy groups.

EXPERIMENTAL

The properties of the compounds prepared are presented in the Table. Compounds (III)-(VI) were prepared by the method of [1] from equivalent amounts of the reagents; (VII) was also prepared by the method of [1] with a ratio of $CH_2{=}CHSiCl_3$ to acetone cyanohydrin of 3:1.

Interaction of methallyldichlorosilane with acetone cyanohydrin. 37 g (0.435 mole) of acetone cyanohydrin was added, over a period of 0.5 hour and with stirring, to 27 g (0.174 mole) of methallyldichlorosilane and 34.4 g (0.435 mole) of pyridine; the temperature of the reaction mixture rose slightly due to exothermic heat, but no precipitate of pyridine salt formed. The contents of the flask were then heated for three hours to incipient boiling of the benzene, and was allowed to stand overnight. The benzene solution was filtered from the precipitate, the benzene was distilled, and the viscous oil, which evolved a gas on standing, was distilled under vacuum. A rough distillation gave the following fractions: 1st fraction, 138-142° (9 mm), 18.2 g; 2nd fraction, 170-172° (9 mm), 3.6 g. (II) was obtained by a second distillation of the first fraction. The material which constituted the second fraction had the following properties: n_D^{20} 1.4390 and d_4^{20} 1.0082, and it was identical with (VI).

The interaction of allyldichlorosilane (0.382 mole) with acetone cyanohydrin (0.9 mole) in the presence of pyridine (0.9 mole) in 400 ml of benzene gave (I) and also a substance with a b.p. of 178-179° (9 mm), n_D^{20} 1.4340, d_4^{20} 1.0132, which was similar to (V); the yield of the latter compound was 27% calculated on the allyldichlorosilane.

When the reactants $CH_2{=}CHCH_2SiCl_2H$, $HOC(CH_3)_2CN$, and C_5H_5N, in amounts of 0.25, 0.5 and 0.5 mole, respectively, and 350 ml of benzene were reacted, (I) was obtained in 67% yield, but no appreciable amounts of (V) were detected.

The interaction of 12.5 g (0.05 mole) of methallyl-di-α-CN-isopropoxysilane with 8.3 g (0.1 mole) of acetone cyanohydrin and 8 g (0.1 mole) of pyridine, by an analogous method but with an eight-hour heating of the reaction mixture to the boiling point of benzene, gave substance (VI) with a b.p. of 160-162° (5 mm), n_D^{20} 1.4394, d_4^{20} 1.0083. The yield was 61.5%.

Methyltri-α-CN-isopropoxysilane was prepared from 23 g (0.2 mole) of methyldichlorosilane, 68 g of acetone cyanohydrin, and 63 g of pyridine in 200 ml of benzene. After the reaction mixture had been heated for 16 hours, the usual treatment gave 27.2 g of a substance with a b.p. of 166-168° (10 mm), n_D^{20} 1.4229, d_4^{20} 1.0177. Literature data [2] for this substance: b.p. 126° (1 mm), n_D^{20} 1.4219, d_4^{20} 1.0155.

Found %: N 14.43, 14.34. $C_{12}H_{21}O_3N_3Si$. Calculated %: N 14.27.

Interaction of dimethyl-α-CN-isopropoxychlorosilane with allyl alcohol. 7.2 g (0.124 mole) of allyl alcohol was added, over a period of 0.5 hour, to a solution of 22 g (0.124 mole) of dimethyl-α-CN-isopropoxychlorosilane and 9.8 g (0.124 mole) of pyridine in 150 ml of benzene. A precipitate appeared after the first drop of allyl alcohol, and the reaction became exothermic. The contents of the flask were stirred for another one hour, and the reaction mixture was then treated by the usual method. The following fractions were obtained by vacuum distillation: 1st fraction, 80-95° (40 mm), 5 g, with a sharp odor; 2nd fraction, 102-108° (40 mm), 10.2 g, also with a sharp odor; 3rd fraction, 92-101° (5 mm), 5.1 g, viscous, odorless oil. Fractionation of the first

Substance No.	Name and structural formula of substance	Yield (%)	Boiling point (pressure in mm)	n_D^{20}	d_4^{20}	MR_D calc.	MR_D found	Empirical formula	N (a %) calc.	N (a %) found
(I)	Allyldi-α-CN-isopropoxysilane $CH_2=CHCH_2SiH[OC(CH_3)_2CN]_2$	33	116—117 (6)	1.4330	0.9697	63.74	63.74	$C_{11}H_{18}O_2N_2Si$	11.75	11.66, 11.97
(II)	Methallyldi-α-CN-isopropoxysilane $CH_2=C(CH_3)CH_2SiH[OC(CH_3)_2CN]_2$	41.5	138—139 (9)	1.4352	0.9653	68.24	68.23	$C_{12}H_{20}O_2N_2Si$	11.09	11.01, 10.95
(III)	Diallyldi-α-CN-isopropoxysilane $(CH_2=CHCH_2)_2Si[OC(CH_3)_2CN]_2$	60.6	139—140 (5)	1.4479	0.9672	77.08	77.04	$C_{14}H_{22}O_2N_2Si$	10.42	10.38
(IV)	Vinyltri-α-CN-isopropoxysilane $CH_2=CHSi[OC(CH_3)_2CN]_3$	48	138 (3)	Cryst. matl., m.p. 36.5°, from ether				$C_{14}H_{21}O_3N_3Si$	13.84	13.43, 13.20
(V)	Allyltri-α-CN-isopropoxysilane $CH_2=CHCH_2Si[OC(CH_3)_2CN]_3$	46	169 (6)	1.4337	1.0127	82.54	82.60	$C_{18}H_{23}O_3N_3Si$	13.40	13.04, 13.21
(VI)	Methallyltri-α-CN-isopropoxysilane $CH_2=C(CH_3)CH_2Si[OC(CH_3)_2CN]_3$	63	158 (4)	1.4392	1.0078	87.04	87.53	$C_{19}H_{25}O_3N_3Si$	12.52	12.51, 12.35
(VII)	Vinyl-α-CN-isopropoxydichlorosilane $CH_2=CHSiCl_2[OC(CH_3)_2CN]$	84	84 (10.5)	1.4390	1.1479	48.13	48.14	$C_6H_9ONCl_2Si$ *	--	--
(VIII)	Dimethylallyloxy-α-CN-isopropoxysilane $(CH_3)_2Si[OCH_2CH=CH_2][OC(CH_3)_2CN]$		105—106 (40)	1.4178	0.9289	54.26	53.91	$C_9H_{17}O_2NSi$	7.02	6.91, 6.88
(IX)	Ethyldiallyloxy-α-CN-isopropoxysilane $C_2H_5Si[OCH_2CH=CH_2]_2[OC(CH_3)_2CN]$		106—108 (4)	1.4294	0.9674	68.44	68.08	$C_{12}H_{21}O_2NSi$	5.52	5.42, 5.25

*Analysis for nitrogen was not carried out. Found % Si 13.28, 13.24. Calculated % Si 13.32.

fraction gave a substance with a b.p. of 86-87° (42 mm), n_D^{20} 1.4172, d_4^{20} 0.8830. Literature data [6] for $(CH_3)_2SI(OCH_2CH=CH_2)_2$: b.p. 155.8° (745 mm), n_D^{20} 1.4170, d_4^{20} 0.8822.

Fractionation of the second fraction gave substance (VI). A second distillation of the third fraction gave $(CH_3)_2Si[OC(CH_3)_2CN]_2$ with a b.p. of 125-127° (21 mm), n_D^{20} 1.4166, d_4^{20} 0.9640. Literature data [3]: b.p. 124-126° (21 mm), n_D^{20} 1.4174, d_4^{20} 0.9644.

(IX) was similarly obtained from equivalent amounts of ethyl-α-CN-isopropoxydichlorosilane, allyl alcohol, and pyridine. The substance (IX) was also separated, with difficulty, from the complex mixture of ethers by fractional distillation.

SUMMARY

1. Seven alkenyl-α-CN-isopropoxysilanes and two allyloxy-α-CN-isopropoxysilanes, none of which have been described in the literature, were synthesized.

2. The feasibility of obtaining alkenyl- and alkyl-α-CN-isopropoxysilanes by the interaction of acetone cyanohydrin with Si—H-containing silanes in the presence of pyridine was demonstrated.

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ORGANOMAGNESIUM SYNTHESIS WITH CARBON SUBOXIDE. I

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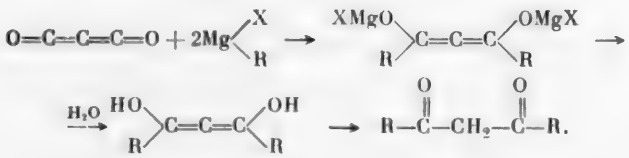
Since carbon suboxide is an unusual ketone and behaves in a manner similar to ketene in many reactions, it might be expected that organomagnesium synthesis by means of carbon suboxide would lead to the production of symmetrical β-diketones according to the scheme:



Our assumption was vindicated; diacetylmethane [2,4-pentanedione], dipropionylmethane [3,5-heptanedione], divalerylmethane [5,7-undecanedione], dibenzoylmethane [1,3-diphenyl-1,3-propanedione], and di(phenylaceto)methane [1,5-diphenyl-2,4-pentanedione] were prepared by means of carbon suboxide. The yields of β-diketones varied within rather wide limits (from 15 to 70%).

EXPERIMENTAL

The ether solutions of carbon suboxide were prepared by the method of Staudinger [1].

Preparation of diacetylmethane. To an ether solution of methylmagnesium iodide, prepared from 8.0 g of methyl iodide, was added 240 ml of an ether solution of carbon suboxide (2.05 g of C_3O_2). The reaction mixture was stirred for half an hour. The organomagnesium complex was then decomposed with hydrochloric acid, the ether layer was separated, and the aqueous layer was extracted with ether. After distillation of the ether, the residue was distilled at 132-135° (according to the literature [2], diacetylmethane has a b.p. of 135-136°). 0.39 g (15%) of the substance (n_D^{20} 1.4539, d_4^{20} 0.9701) was obtained. A qualitative reaction with ferric chloride for the presence of an enol group was positive. The amide of 3,5-dimethylpyrazole-1-carboxylic acid, m.p. 111-112°, was prepared from the diacetylmethane; the m.p. is in agreement with the literature value [2].

Dipropionylmethane was prepared by the above method from 5.5 g of ethyl bromide and 180 ml of an ether solution of carbon suboxide (1.50 g of C_3O_2). 1.4 g (50%) of a fraction boiling at 72-74° (25 mm), n_D^{20} 1.4050, d_4^{20} 0.9444, was obtained. According to the literature [3], dipropionylmethane has a b.p. of 80° (30 mm). The test for the enol group was positive.

Divalerylmethane was prepared from 8.0 g of butyl chloride and 130 ml of an ether solution of carbon suboxide (1.0 g of C_3O_2). 1.2 g (51%) of the material was obtained; n_D^{20} 1.4567, d_4^{20} 0.9258, b.p. 84-86° (17 mm), which is in approximate agreement with the literature value [4]. The test for the enol group was positive.

Dibenzoylmethane was prepared from 15 g of bromobenzene and 60 ml of an ether solution of carbon suboxide (0.5 g C_3O_2). After distillation of the ether and treatment of the oily residue with 20% NaOH, crystals were obtained with an m.p. of 71-73°, which is in agreement with the literature value [5]. The qualitative test for the presence of the enol group was positive. The yield was 0.93 g (65%).

Di(phenylaceto)methane was prepared from 13 g of benzyl chloride and 60 ml of an ether solution of carbon suboxide (0.48 g of C_3O_2). The resulting oily residue soon crystallized. M.p. 51-52° (from 70% ethyl alcohol). The test for the enol group was positive. The yield was 1.03 g (68%).

Found %: C 12.40; H 6.06. M (Rast) 250. $C_{17}H_{16}O_2$. Calculated %: C 12.70; H 6.35. M 252.

The complete analogy with the preceding reactions and the analytical data confirm that the synthesized substance was di(phenylaceto)methane.

SUMMARY

1. It was shown that the interaction, in the cold and in an ethereal medium, of carbon suboxide with organomagnesium halides results in the formation of symmetrical aliphatic and aromatic β-diketones.

2. In individual cases, the interaction of carbon suboxide with organomagnesium halides can apparently serve as a method for the preparation of symmetrical β-diketones.

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THE EFFECT OF LOW MOLECULAR WEIGHT MATERIALS ON THE PHOTOCHEMICAL DEGRADATION OF POLYETHYLENE TEREPHTHALATE

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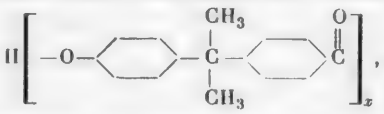
Up to the present time, the literature has presented only a small amount of information on the photochemical degradation of polyesters in general and of polyethylene terephthalate in particular. Griehl [1] reported on the changes in the tensile strength of certain fibers occurring under the influence of ultraviolet irradiation. In comparison with Perlon and viscose silk, polyethylene terephthalate displayed the least drop in tensile strength. According to the data of Coleman [2], the intrinsic viscosity of a polyethylene terephthalate sample changed by only 1-1.5% after a 300-hour irradiation with ultraviolet light. Under the same conditions, the intrinsic viscosity of a copolymer of polyethylene terephthalate and polyethylene glycol changed by 40%. The results of an investigation of the stability to light of 1C-312 and 1C-312-2 polyesters have been published [3]. The compositions of these polyesters were not reported. The absorption of these polyesters in the ultraviolet region lay in the region of 3500 A. The absorption in this region of the spectrum increased with an increase in the duration of the irradiation. A number of compounds were investigated with the aim of finding the best stabilizers. The most effective stabilizers were derivatives of o-hydroxybenzophenone. Salol exhibited the best protective effect. There have also been reports that organic compounds having a functionality greater than two are stabilizers for linear polyesters. Such compounds must contain ester groups [4]. Schnell [5] presented data on the effects of the irradiation of polycarbonate films,  , prepared from 2,2-(4,4'-dihydroxydiphenyl)propane and phosgene. The mechanical properties of the film samples had not changed after 72 hours of irradiation with a Hanau-300 lamp placed at a distance of 29 cm from the sample and at an angle of 45°. These data represent the extent of the information available in the literature on the photochemical degradation of polyesters.

In the present investigation, we studied the changes in the properties of polyethylene terephthalate (Lavsan) caused by the action of the total radiation from a PRK-2 lamp and also by the action of a narrower portion of the spectrum, the portion lying in the range 300-320 mμ (the mercury line is at 313 mμ). At the same time, an attempt was made to follow the effect of certain low molecular weight compounds on the course of the changes in the properties of polyethylene terephthalate under the influence of ultraviolet irradiation.

The absorption spectra of the samples of polyethylene terephthalate film at our disposal were not uniform, but varied somewhat from sample to sample. Sometimes, a uniform absorption down to 310 mμ was observed; at other times, weak maxima in the absorption spectra were noted at 345 and 428 mμ. These data differ somewhat from the published data [6], and this can apparently be explained by certain differences in the composition of the polyesters.

In order to clarify the effect of low molecular weight organic compounds on the course of the photochemical degradation of polyethylene terephthalate, substances with different structures were used [7]. Each of these compounds absorbed in the region of 250-320 mμ, and the absorption extended further into the region of longer wavelengths. The additives used in the present investigation were salol, the diethyl ester of dihydroxyterephthalic acid, 8-methylumbelliferone, and 2-o-hydroxyphenylbenzoxazole. The absorption spectra of these compounds were presented in a previous communication [7].

The organic compounds were introduced into the finished polyethylene terephthalate films. For this purpose, the samples of film were swollen in solutions containing the required substances. The amount of material introduced into the film was not determined accurately. The penetration of the organic compound into the polymer film could be estimated only qualitatively by the change in the color of the luminescence of the film sample after swelling corresponded to the color of the luminescence of the substance serving as the additive. The prepared film samples were tested under the same conditions as the samples of polyester containing no additive.

As was indicated above, irradiation of the samples was by a PRK-2 quartz mercury lamp. The effect of wavelengths in the 300-320 mμ region was investigated separately. This region was of interest to us, because the 300-320 mμ region of the solar spectrum has a high intensity, and the behavior of the polyethylene terephthalate films toward the action of waves of this length permitted estimation, to a certain extent, of the stability of the polymer toward exposure to sunlight.

Changes in the molecular weight, the mechanical properties, and the spectral characteristics were determined after irradiation of the film samples with ultraviolet light.

EXPERIMENTAL

Samples of the polyethylene terephthalate film, with a thickness of 30-40 μ and oriented in the longitudinal direction, were submerged in a 1% solution of the organic compound in a mixture of Chlorex and ethyl alcohol (2:3). The swelling time of the films in the solution was 18 hours. After the expiration of this period, the samples were taken from the solution, washed well with alcohol, dried in air, and stored in the dark. Some of the experiments were repeated with samples of polyethylene terephthalate film, the thickness of which was also 30-40 μ. These samples were submerged in the solution of the additive for only three hours. In specific cases, the organic compound used as the additive was dissolved in a mixture of Chlorex and ethyl alcohol taken in a ratio of 1:3. In these experiments, diethyl 2,5-dihydroxyterephthalate and 2-o-hydroxyphenylbenzoxazole served as the additives.

Irradiation of the film samples was carried out at 20° with light from a PRK-2 lamp placed at a distance of 50 mm from the sample. The length of the irradiation was 10 hours. In order to maintain this regime, the entire apparatus was placed in a glass, thermostatted bath filled with distilled water. The 300-320 mμ region was separated from the total spectrum of the quartz-mercury lamp by means of a liquid filter which was poured into the bath together with the distilled water [7]. The irradiation time of the samples was 100 hours in the first experiments and 50 hours in the repeat experiments.

Samples of the film before and after irradiation were tested in a Poliani-type dynamometer [as in Russian] to determine tensile strength and elongation. Elongation of the film was across the orientation of the polymer.

The molecular weight of the polyethylene terephthalate was determined by the viscosimetric method. For this purpose, the viscosity of an 0.5% solution of the polymer (film) in m-xylene was determined at 25°. The equation proposed by Turska-Kusmiery and Skwarski [8] was used to calculate the molecular weight:

$$[\eta] = 5.517 \cdot 10^{-4} \cdot M^{0.709},$$

$[\eta] = \eta_{sp}/c/(1 + 0.66\eta_{sp})$, where c is the concentration, 0.5%.

The change in the absorption spectra was determined for the samples of the film before and after irradiation.

The absorption spectra of the samples were taken with a spectrophotometer with a high-speed recording attachment.

DISCUSSION OF RESULTS

Ten-hour irradiation of polyethylene terephthalate film with light from a PRK-2 quartz-mercury lamp under the conditions of our experiments undoubtedly leads to degradation of the polymer. This is indicated primarily by the mechanical properties of the film and, chiefly, by the elongation at break. As seen from Figs. 1 and 2, the elongation at break of two samples of polyethylene terephthalate film of different thickness decreased by a factor of 6-8 after a ten-hour exposure as compared to the original value. The tensile strength of the samples also decreased after exposure, but less significantly than the elongation. As a practical matter, the samples became less elastic, brittle, and unsuitable for use. The molecular weight of the exposed samples decreased from 14,300 to 12,000.

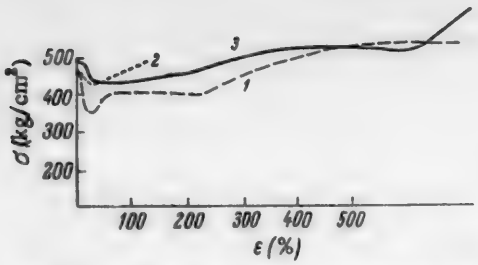


Fig. 1. Elongation curves for a sample of polyethylene terephthalate (0.003 cm): 1) before irradiation; 2) after 10-hour exposure to a PRK-2 lamp; 3) after 50-hour exposure to 300-320 mμ radiation.

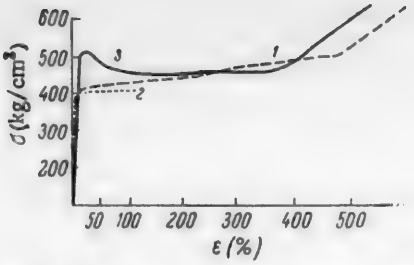


Fig. 2. Elongation curves of a sample of polyethylene terephthalate (0.01 cm): 1) before exposure; 2) after 10-hour exposure to a PRK-2 lamp; 3) after 50-hour exposure to 300-320 mμ radiation.

In addition, it must be pointed out that during the course of the photochemical degradation of polyethylene terephthalate, we did not observe the formation of insoluble material. It is quite probable that the polymer molecule, under the influence of photons, breaks down into small fragments, and the formation of an insoluble three-dimensional product, if it proceeds at all, does so to a very slight extent.

The intensity of the absorption in the ultraviolet region of the spectrum increased slightly with an increase in exposure, and the appearance of maxima was noted in the region of 330-344 mμ (Fig. 3). These results are in agreement with data presented in the literature for other polyesters [3]. The increase in the intensity of the absorption in the ultraviolet region of the spectrum after exposure of the polymer can apparently be explained by the appearance of more unsaturation caused by the decomposition of the molecule as a result of photochemical degradation. Moreover, the absorption was shifted further into the visible part of the spectrum, which also confirms the appearance in the polymer molecule of new bonds, possibly aromatic in character. The effect of exposure to radiation in the 300-320 mμ region is very slight, and is indicated chiefly by somewhat of a decrease in the tensile strength of the samples.

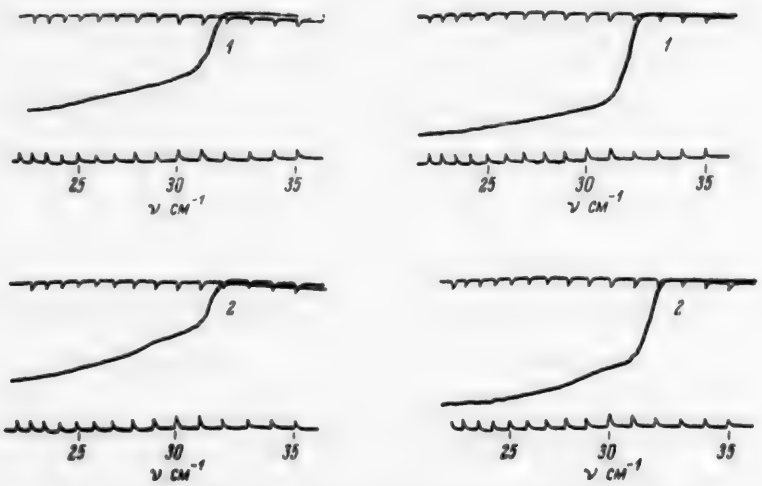


Fig. 3. Absorption spectra of two samples of polyethylene terephthalate films: 1) before exposure; 2) after 10-hour exposure to a PRK-2 lamp.

Before proceeding to a discussion of the results obtained with samples of polyethylene terephthalate with added organic compounds, we should pause for a moment to consider the effect of the solvents used for swelling the films on the properties of these films before exposure. As already noted, a mixture of Chlorex and alcohol

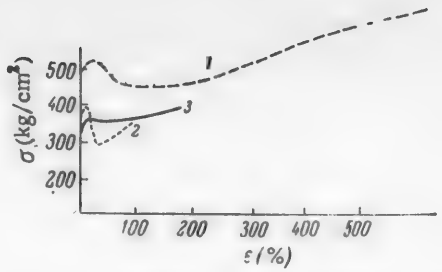


Fig. 4. Elongation curves for polyethylene terephthalate samples (0.01 cm) treated with solvent: 1) before exposure; 2) after 10-hour exposure to a PRK-2 lamp; 3) after 50-hour exposure to 300-320 mμ radiation.

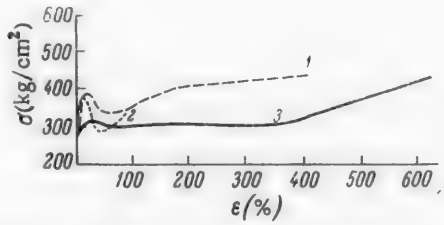


Fig. 5. Elongation curves for the sample of polyethylene terephthalate with 2-o-hydroxyphenylbenzoxazole additive: 1) before exposure; 2) after 10-hour exposure to a PRK-2 lamp; 3) after 50-hour exposure to 300-320 mμ radiation.

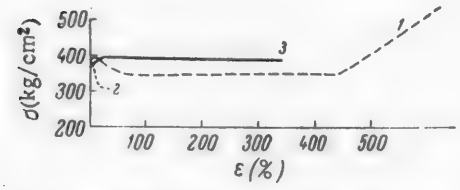


Fig. 6. Elongation curves of a polyethylene terephthalate sample (0.01 cm) with diethyl dihydroxyterephthalate additive: 1) before exposure; 2) after 10-hour exposure to a PRK-2 lamp; 3) after 50-hour exposure to 300-320 mμ radiation.

in two different ratios, namely, 2:3 and 1:3, were used during the course of the investigation. The soaking time of the films was also varied from 18 hours in the first case to three hours in the second case. We established that the solvent undoubtedly has an effect on the properties of polyethylene terephthalate, even before exposure of the polymer to ultraviolet irradiation. The mechanical properties of the samples of polyethylene terephthalate film were appreciably worse after swelling, the mixture containing Chlorex and alcohol in a 2:3 ratio having the greater effect.

In Fig. 4 are presented the results of the irradiation of samples of polyethylene terephthalate film treated with a mixture of Chlorex and alcohol (1:3). The additives introduced into the film samples decreased the tensile strength of the films in comparison with the samples treated with solvent alone. In addition, the elasticity of the films containing additives was slightly lower than that of the solvent-treated samples; this indicates some incompatibility of the polyester and the substance used (see Table). As would be expected, the effect of the addition of organic compounds was developed only in samples exposed to light in the region of 300-320 mμ.

β-Methylumbelliferone displayed no stabilizing effect against the process of photochemical degradation of the polyethylene terephthalate. This appeared as a deterioration of the mechanical properties of the exposed samples containing this additive (see Table). The absorption spectrum of this same sample after exposure showed a small increase in absorption in the ultraviolet region. The results of a previous investigation [7] showed that β-methylumbelliferone decomposes under the conditions of the experiment. We assume that, since the experimental conditions were unchanged in the present case, the β-methylumbelliferone undoubtedly behaved the same, and, decomposing under the action of photons, formed free radicals which accelerated the degradation of the polyester.

The addition of salol caused some improvement of the mechanical properties of the film after exposure. The break strength and deformation were increased in comparison with the unexposed film sample. As has already been indicated, the protective properties of salol with respect to polyesters has been reported in the literature [3]. However, salol has an unfavorable effect on the mechanical properties of polyethylene terephthalate before exposure, appreciably decreasing the tensile strength of the sample. Absorption in the ultraviolet region of the spectrum did not increase after exposure of the sample containing salol. The positive effect displayed by salol on exposure of the polyethylene terephthalate to 300-320 mμ radiation can be explained on the basis that, being an inhibitor, it can slow down the development of free radicals during the course of their formation under the action of radiation. Dwelling for a moment on the positive effect displayed by salol, it seems to us desirable to recall the results presented in a previous communication [7]. In this investigation, a positive, but only insignificant effect of salol on the course of the photochemical degradation of polystyrene was detected.

Results of Mechanical Tests on Samples of Polyethylene Terephthalate Before and After Exposure*

Sample No.	Film sample tested	Film thickness (in cm)	Before exposure		After exposure to u.v. from PRK-2 lamp (10 hrs)		After exposure to 300-320 mμ radiation**	
			ε (%)	σ (kg/cm²)	ε (%)	σ (kg/cm²)	ε (%)	σ (kg/cm²)
1	Film without additive	0.01	560	606	104	403	385	513
2	Film without additive	0.003	660	628	79	448	609	635
3	Film No. 1 treated with a mixture of Chlorex and alcohol (1:3) for 3 hours	0.01	686	534	43	329	207	400
4	Film No. 1 treated with the same Chlorex-alcohol mixture for 3 hours. Additive – diethyl dihydroxyterephthalate	0.01	505	460	90	350	348	384
5	Film.No. 1 treated with the same Chlorex-alcohol mixture for 3 hours. Additive – 2-o-hydroxyphenylbenzoxazole	0.01	215	400	4	350	610	433
6	Film treated with Chlorex-alcohol mixture (2:3) for 18 hours. Additive – diethyl dihydroxyterephthalate	0.004	13	309	6	292	51***	275
7	Film treated with Chlorex-alcohol mixture (2:3) for 18 hours. Additive – 2-o-hydroxyphenylbenzoxazole	0.004	46	1005	12.1	655	60	934
8	Film treated with Chlorex-alcohol mixture (2:3) for 18 hours. Additive – salol	0.004	27	701	23	650	62	830
9	Film treated with Chlorex-alcohol mixture (2:3) for 18 hours. Additive – β-methylumbelliferone	0.004	34	983	3.5	648	19	862

*Elongation rate of Samples 1-5 was 0.073 mm/sec, of Samples 6-9 – 0.008 mm/sec.

**Exposure time for Samples 1-5 was 50 hours, for Samples 6-9 – 100 hours.

***This sample elongated at a rate of 0.072 mm/sec.

2-o-Hydroxyphenylbenzoxazole displayed some protective action (see Table). It should be pointed out that this compound had little effect on the photochemical degradation of polystyrene, contributing only to the process of structure formation [7] (Fig. 5).

Diethyl dihydroxyterephthalate displayed a slight sensitizing effect on the course of the photochemical degradation of polyethylene terephthalate (Fig. 6). Just as in the preceding communication, we attribute this effect to the absence of absorption in the region of 250-320 mμ by diethyl dihydroxyterephthalate This is apparently also the chief reason that diethyl dihydroxyterephthalate has no inhibiting properties and is incapable of slowing down the photochemical degradation of polyethylene terephthalate.

For their aid in the recording of the absorption spectra and in the determination of the mechanical properties, the authors express their deep appreciation to I.V. Obreimov, G.L. Slonimskii, I.Ia. Kachkurova, L.Z. Rogovina and T.A. Dikareva.

SUMMARY

1. The degradation of polyethylene terephthalate under the influence of ultraviolet irradiation was investigated.

2. It was found that degradation of polyethylene terephthalate proceeds considerably more intensely under the influence of the total ultraviolet radiation from a PRK-2 lamp than under the influence of light with a wavelength of 300-320 mμ.

3. The introduction into polyethylene terephthalate of low-molecular-weight organic compounds as additives has an effect on the degradation of the polyester.

4. The results are in agreement with the results obtained in the investigation of the effect of these same additives on the course of the degradation of polystyrene.

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THE INTERACTION OF PHENYLPHOSPHORUS TETRACHLORIDE WITH DIAZOMETHANE

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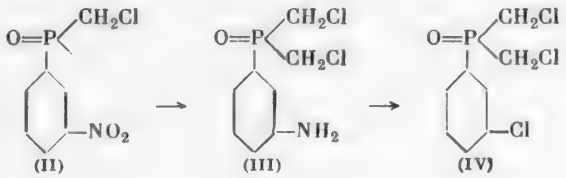
The reaction of aliphatic diazo compounds with phosphorus halogen compounds has been studied by Iakubovich and Ginsburg [1]. They showed that phosphorus trichloride and pentachloride react with diazomethane at temperatures of −60 to −40°. In the case of phosphorus trichloride, the reaction stops at the stage of the monoalkyl derivative – chloromethylphosphorus dichloride is formed; with phosphorus pentachloride, the reaction proceeds to the trialkyl derivative – trichlorotrimethylphosphine is formed.

It was of interest to investigate the reaction of arylphosphorus tetrachloride with diazomethane. It was found that phenylphosphorus tetrachloride reacts very readily with diazomethane at −40°. Hydrolysis of the product gave ω,ω'-dichlorodimethylphenylphosphine oxide. The reaction apparently proceeds through a stage in which the readily hydrolyzable ω,ω'-dichlorodimethylphenyl dichloride is formed.

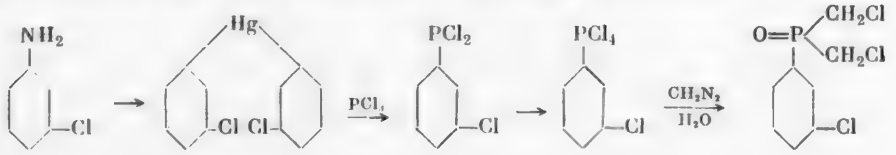
$$C_6H_5PCl_4 + 2CH_2N_2 \rightarrow N_2 + [C_6H_5P(CH_2Cl)_2Cl_2] \xrightarrow{H_2O} \underset{(I)}{C_6H_5\overset{\overset{O}{\|}}{P}(CH_2Cl)_2}$$

The dichlorodimethylphenylphosphine oxide (I) was in the form of colorless prisms. It was readily soluble in alcohol and acetone, difficultly soluble in benzene, and sparingly soluble in water. The chlorine atoms in the chloromethyl groups enter into exchange reactions only with difficulty. They can be replaced by iodine by means of potassium iodide, but only under rigorous conditions – in boiling glycol. The nitration of (I) can be carried out by heating with the nitrating mixture on a boiling-water bath. The nitro group enters the meta position. This was proved as follows. The nitro group was reduced to an amino group, and the latter was replaced with chlorine by the Sandmeyer reaction.



(II) (III) (IV)

This same product was prepared by alternate synthesis according to the scheme:



A mixture of these substances showed no depression of the melting point.

Therefore, the $O=P<^{CH_2Cl}_{CH_2Cl}$ group is meta orienting.

EXPERIMENTAL

ω ω'-Dichlorodimethylphenylphosphine oxide (I). 150 ml of absolute ether and 25 g (0.1 mole) of phenylphosphorus tetrachloride [2], prepared from phenyldichlorophosphine [3] and chlorine, were charged to a reactor fitted with a stirrer, a dropping funnel, a thermometer, and a condenser connected to a calcium chloride tube. The mixture was cooled to −40°, and at this temperature, a solution of 9.7 g (0.23 mole) of diazomethane in 300 ml of ether was added over the course of an hour; the diazomethane solution was precooled to −2° and dried successively over KOH and sodium wire. After the addition of half of the diazomethane solution, a colorless sludge formed. At the conclusion of the addition of the diazomethane, stirring was continued for 30 minutes at a temperature of −40 to −35°, and then the reaction mixture was allowed to stand overnight at 0°. On the following day, without separating the sludge, the ether was distilled on a water bath, and the residue was added to 500 ml of water. Foaming occurred and heat was evolved during the addition. After a day, the product was suction filtered, washed with water, dried, and crystallized from methyl alcohol. The yield was 7.0 g (31.4%). M.p. 141-142°.

Found %: Cl 32.13, 32.31. $C_9H_9OPCl_2$. Calculated %: Cl 31.83.

ω,ω'-Dichlorodimethyl-(m-nitrophenyl)phosphine (II). The nitrating mixture [9.9 g of HNO_3 (d 1.5) and 16.1 g of H_2SO_4 (d 1.83)] was placed in a flask with a ground-glass joint, cooled to 0°, and, with stirring, 5.58 g of (I) was gradually added. A reflux condenser was joined to the flask, and the flask and contents were heated on a boiling water bath for 45 minutes. The solution was cooled and poured onto ice. The product was filtered and washed with water. Recrystallization from methyl alcohol or benzene resulted in light-yellow prisms with a m.p. of 155-156°. The yield was 6 g (93%). (II) is readily soluble in hot methyl and ethyl alcohols and benzene, but very slightly soluble in the cold solvents.

Found %: N 5.25, 5.32; Cl 26.51, 26.63. $C_9H_8O_3NPCl_2$. Calculated %: N 5.22; Cl 26.49.

ω,ω'-Dichlorodimethyl-(m-aminophenyl)phosphine oxide (III). A solution of 5.36 g (0.02 mole) of (II) in 50 ml of ethyl alcohol was placed in a reactor fitted with a stirrer, a dropping funnel, a reflux condenser, and a thermometer; the solution was heated on a water bath to 70°, and a solution of 15.9 g (0.07 mole) of $SnCl_2 \cdot 2H_2O$ in 10 ml of HCl (d 1.19) was added dropwise over a period of 30 minutes. The mixture was heated at this temperature for one hour, and then refluxed for 15 minutes. The alcohol was distilled under the vacuum of a water aspirator. An excess of 30% alkali was added to the residue. The product was extracted with ether (five times with 40-50 ml portions). The ether solution was dried, and the ether was distilled. The yellowish prisms were recrystallized from benzene. The yield was 2.33 g (56%). M.p. 110-111°. The product was readily soluble in alcohol and hot benzene and sparingly soluble in cold benzene.

Found %: N 6.10, 6.15; Cl 29.54, 29.98. $C_9H_{10}ONPCl_2$. Calculated %: N 5.88; Cl 29.82.

Prisms of the acetyl derivative were recrystallized from water; m.p. 163-164°.

Found %: N 5.13, 5.16. $C_{10}H_{12}O_2NPCl_2$. Calculated %: N 5.0.

ω,ω'-Dichlorodimethyl-(m-chlorophenyl)phosphine oxide (IV). 0.72 g (0.003 mole) of (III) was dissolved in 2 ml of 20% HCl; the solution was cooled to −3°, and diazotized with a solution of 0.22 g (0.003 mole) of sodium nitrite in 2 ml of water. A solution of 0.4 g (0.004 mole) of cuprous chloride in 3 ml of 30% hydrochloric acid was prepared, and, with vigorous stirring, the solution of diazonium salt was added to the cuprous chloride solution. The reaction proceeded violently. The mixture was allowed to stand at room temperature. On the following day, the mixture was heated at 60° for 30 minutes. The product was cooled, filtered, washed with water, and dried. White crystals were obtained by recrystallization from water. The yield was 0.4 g (52%). M.p. 129-130°. The product was readily soluble in alcohol and benzene, more difficultly soluble in hot water, and sparingly soluble in cold water.

Found %: Cl 41.65, 41.75. $C_8H_8OPCl_3$. Calculated %: Cl 41.36.

Di(m-chlorophenyl)mercury. A solution of 57 g (0.21 mole) of mercuric chloride in 75 ml of hydrochloric acid (d 1.19) was placed in a reactor fitted with a stirrer and thermometer. The solution was cooled with an ice-

salt mixture, and 75 g of finely crushed ice was added. A solution of 17.5 g (0.25 mole) of sodium nitrite was added, with stirring, at a rate such that the temperature did not rise above −5°. A cooled solution of 25.5 g (0.2 mole) of m-chloroaniline in 100 ml of ether was then added rapidly. The mixture was stirred vigorously for 15 minutes, and the product was filtered and washed with water, alcohol, and ether. The yield of the double salt of chlorobenzenediazonium chloride and mercuric chloride was 70 g. 20 g (0.32 g-atom) of copper powder and 100 ml of acetone were placed in a flask fitted with a stirrer. The mixture was cooled to −5°, and 22.3 g (0.05 mole) of the double salt was added. The reaction began at 0°. Exothermic heat raised the temperature to 13°. Ten minutes after the reaction had subsided, 100 ml of 25% aqueous ammonia was added. On the following day, the mixture was refluxed for two hours and diluted with water to 700 ml. After two hours, the precipitate was filtered and washed on the filter with water and a small amount of ether. The organomercury compound was extracted from the precipitate with ether (four times with 100-ml portions). The chloroform was distilled. Silvery crystals were obtained by recrystallization from alcohol. The yield was 3.12 g (23%). M.p. 148-149°. Di-(m-chlorophenyl)mercury is readily soluble in hot benzene, chloroform, alcohol and acetone.

Found %: Cl 16.44, 16.51. $C_{12}H_8Cl_2Hg$. Calculated %: Cl 16.52.

m-Chlorophenylphosphorus dichloride. 0.5 g (0.02 mole) of di(m-chlorophenyl)mercury and 25 g (0.18 mole) of PCl_3 were sealed in a tube and heated at 230-250° for 24 hours. The tube was opened, and the liquid was rapidly filtered through a Nutsch filter. The tube and the precipitate were washed with absolute petroleum ether. The petroleum ether was distilled, and the liquid residue was distilled under vacuum. The yield was 6.8 g; b.p. 101-103° (5 mm). The liquid was filtered through a No. 4 glass filter and again vacuum distilled to remove the mercuric chloride.

m-Chlorophenylphosphorus dichloride is a liquid with a disagreeable odor; it is readily soluble in C_6H_6 and CCl_4 and less soluble in petroleum ether; it is hydrolyzed by cold water.

Found %: Cl, after hydrolysis, 33.06, 33.15. $C_6H_4PCl_3$. Calculated %: Cl, after hydrolysis, 33.26.

m-Chlorophenylphosphorus tetrachloride. 2.14 g of m-chlorophenylphosphorus dichloride was placed in a flask. Dry chlorine was passed through a tube which opened over the surface of the liquid until the theoretical amount (0.71 g) was absorbed; the flask was cooled periodically with water. Dry CO_2 was then passed into the flask. The product crystallized from solution. The melting point of the raw product was 46-47° in a sealed capillary. The yield was 2.75 g (quantitative).

Found: equiv. (after hydrolysis) 5.99. $C_6H_4PCl_5$. Calculated: equiv. 6.

ω,ω'-Dichlorodimethyl-(m-chlorophenyl)phosphine oxide. This compound was prepared by the same method as (I). From 2.8 g (0.01 mole) of m-chlorophenylphosphorous tetrachloride in 30 ml of ether and 1.1 g (0.025 mole) of diazomethane in 100 ml of ether was obtained, after crystallization from water containing carbon, 0.7 g (31%) of product with a m.p. of 129°.

ω,ω'-Diiododimethylphenylphosphine oxide. 2.23 g (0.01 mole) of (I), 4.4 g (0.026 mole) of KI, and 18 ml of glycol were placed in a flask with a ground-glass joint and fitted with a reflux condenser and calcium chloride tube; the mixture was refluxed for six hours, cooled, and poured onto ice. The product was filtered. White prisms were obtained by recrystallization from aqueous alcohol. The yield was 2.5 g (61.5%). M.p. 172-173°. The product was soluble in methyl and ethyl alcohol on heating.

Found %: I 62.50, 62.60. $C_8H_9OPI_2$. Calculated %: I 62.56.

SUMMARY

Phenylphosphorus tetrachloride reacts with diazomethane to yield ω,ω'-dichlorodimethylphenylphosphine oxide. The ω,ω'-dichlorodimethylphenylphosphine oxide group is meta orienting during electrophilic substitution in an aromatic ring.

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SYNTHESIS OF 6-BROMO-8-MERCAPTOQUINOLINE (6-BROMOTHIOOXINE) AND SOME OF ITS PROPERTIES

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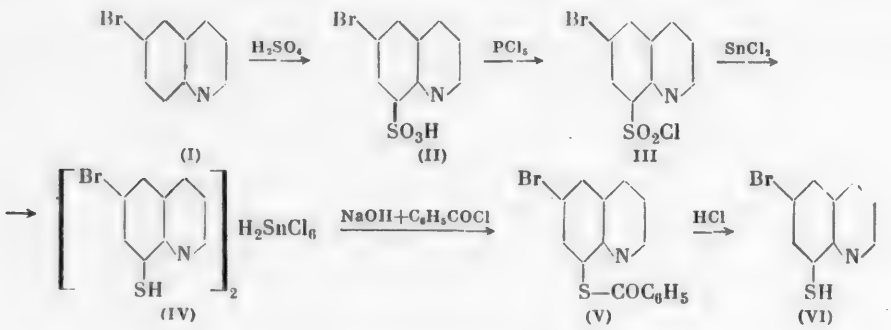
As shown by investigations currently in progress, 8-mercaptoquinoline (thiooxine) is a good analytical reagent for the colorimetric determination of metals – copper, palladium, molybdenum, manganese, vanadium, and others [1]. Derivatives of 8-mercaptoquinoline are also of interest as possible analytical reagents, since the presence of substituents on the quinoline ring could have an effect on the properties of the functional atomic groups and thereby change the analytical quality of the reagent.

The synthesis of 8-mercaptoquinoline and 5-bromo-8-mercaptoquinoline was accomplished by Edinger [2] and improved by one of us [3]. The preparation of 4-chloro-8-mercaptoquinoline was described later [4]. The preparation of 6-bromo-8-mercaptoquinoline is described in the present communication. Following the method of A. Edinger, the synthesis of 6-bromo-8-mercaptoquinoline (VI) can be represented by the following scheme:



EXPERIMENTAL

6-Bromoquinoline was prepared by the method of Skraup from p-bromoaniline [5].

Preparation of 6-bromoquinoline-8-sulfonic acid. The sulfonation of 6-bromoquinoline was carried out by the method described for the preparation of quinoline-8-sulfonic acid [6], except that the 6-bromoquinoline was first converted by the calculated amount of concentrated sulfuric acid to the sulfate. The latter was gradually added in small portions to a three-fold amount (calculated on the weight of 6-bromoquinoline) of 60% oleum. This procedure kept the evolution of heat and the loss of SO_3 to a minimum. 55 g of 6-bromoquinoline was gradually added, with stirring, to 26 g of concentrated sulfuric acid. Over a one-hour period, small portions of the solidified 6-bromoquinoline sulfate were added, with agitation, to 160 g of 60% oleum. The reaction mixture was held at 170° for five hours in a flask connected to a reflux condenser by means of a ground-glass joint. The contents of the flask were cooled, poured into 800 g of ice, and allowed to stand overnight. The 6-bromoquinoline-8-sulfonic acid was separated and washed two to three times with water; the yield was 70 g (79%).

For preparation of the sodium salt, the 6-bromoquinoline-8-sulfonic acid was suspended in 0.5 liter of water and neutralized (to a pH of about 7) by heating with a 20% solution of NaOH (the pH was determined with universal indicator paper). The solution was evaporated, and the sodium salt was dried at 160° and carefully ground.

6-Bromoquinoline-8-sulfonyl chloride. 74 g of the sodium salt of 6-bromoquinoline-8-sulfonic acid was carefully mixed with 70 g of ground phosphorus pentachloride, and the mixture was heated in a flask on an oil bath. The reaction began at a temperature of about 100°, and the mixture became liquid owing to the formation of phosphoryl chloride. The temperature of the bath was raised to 140-145°, and the reaction mixture was held at this temperature for 10-20 minutes to the beginning of solidification. Then, before the melt solidified in the flask, it was poured into a large porcelain mortar, distributed in a smooth layer, and, at the instant of setting, it was scraped from the sides of the mortar with a porcelain spatula and ground as carefully as possible. After the 6-bromoquinoline-8-sulfonyl chloride had cooled completely, 300 ml of water and ice was poured into the mortar, and grinding of the solid lumps was continued to separate out the phosphoryl chloride and to leach out the sodium chloride. After 10-15 minutes, the sulfonyl chloride was suction filtered, washed with ice water, and carefully pressed. 93 g of moist sulfonyl chloride was obtained.

Reduction of 6-bromoquinoline-8-sulfonyl chloride. The 6-bromoquinoline-8-sulfonyl chloride was reduced with stannous chloride on the same day in which it was prepared since it undergoes decomposition when moist. 210 g of $SnCl_2 \cdot 2H_2O$ (analytical grade) was dissolved in 300 ml of concentrated hydrochloric acid. The sulfonyl chloride was then dissolved in 300 ml of concentrated hydrochloric acid. This solution was prepared at the very last moment, since the sulfonyl chloride rapidly decomposes when dissolved in hydrochloric acid. The slowly dissolving lumps of 6-bromoquinoline-8-sulfonyl chloride remaining on the bottom of the flask were ground, and, without waiting for them to dissolve completely, the solution was poured in a thin stream, with stirring, into the solution of stannous chloride. When the solutions had mixed, the mixture was warmed, and a lemon-yellow crystalline precipitate of the complex of stannic chloride with 6-bromo-8-mercaptoquinoline formed. The stannic chloride salt was cooled, filtered on a Büchner funnel, washed with 50 ml of hydrochloric acid (1 : 1) and then with water, and carefully pressed. 176 g of the moist stannic chloride salt was obtained.

Decomposition of the stannic chloride complex with 6-bromomercaptoquinoline-8-sulfonyl chloride and preparation of the benzoyl derivative. To 176 g of the stannic chloride salt obtained in the preceding experiment was added, in small portions and with stirring, a solution of 50 g of NaOH in the least possible amount of water until a homogeneous mass was formed. 0.5 liter of water was added, and the mixture was brought to boiling, after which it was diluted with another 0.5 liter of water. The yellow precipitate went into solution. The dark-yellow, turbid solution was filtered. If an appreciable amount of undecomposed stannic chloride salt remained on the filter, the treatment with alkali was repeated using a more dilute solution. The dark-yellow filtrate, which gradually became turbid, was cooled, poured into a large bottle with a ground-glass stopper, and vigorously agitated with small portions (2-3 ml) of benzoyl chloride until the solution was decolorized. During this procedure, it was necessary constantly to follow the pH of the medium (by means of universal indicator paper); the medium must be strongly alkaline (pH $\approx$ 10). If the pH dropped too low, 20-30 ml of a 20% solution of NaOH was added. A yellow, grainy precipitate of the benzoyl derivative of 6-bromo-8-mercaptoquinoline formed; the precipitate was filtered and washed with a dilute solution of alkali and then with water.

Decomposition of the benzoyl derivative and isolation of 6-bromo-8-mercaptoquinoline. The benzoyl derivative obtained in the preceding experiment was refluxed with 350 ml of concentrated hydrochloric acid in a 500-ml flask joined to a reflux condenser by means of a ground-glass joint. The mixture was slowly boiled, and after approximately 40-60 minutes, complete decomposition of the benzoyl derivative occurred with the formation of a transparent, dark-yellow solution. The solution was cooled over a period of 2-3 hours, and the precipitated coarse crystals of benzoic acid were filtered and washed with a small amount of hydrochloric acid (1 : 1).

The yellow filtrate (a hydrochloric acid solution of 6-bromo-8-mercaptoquinoline) was transferred to a 2-liter flask, the flask was placed in an ice bath, and the contents were neutralized (as indicated by universal indicator paper) with a saturated, carefully filtered solution of sodium carbonate (130 g of Na_2CO_3 in 300 ml of water). Dark-red crystals of 6-bromo-8-mercaptoquinoline precipitated when the pH reached 5.5-6. Occasionally, when the solution was insufficiently cooled during neutralization, the 6-bromo-8-mercaptoquinoline separated in the form of a heavy, blue oil, which crystallized after some time. The crystals were suction filtered, washed several times with water, and dried at room temperature on a sheet of filter paper. The yield was 15 g (19%). Analysis of the purified preparations indicated that the material contained two molecules of water of crystallization.

Found %: H 3.69; N 4.94; S 11.48. $C_9H_6NSBr \cdot 2H_2O$. Calculated %: H 3.62; N 5.06; S 11.58.

6-Bromo-8-mercaptoquinoline is very sparingly soluble in water (with the formation of a yellow-orange solution); it is soluble in ethyl alcohol and in ether to the extent of about 0.6 g and 10 g per 100 ml, respectively; it is soluble in other water-miscible solvents (acetone, dioxane). It is extracted from aqueous solutions by water-immiscible organic solvents. The extracts have a yellow or orange color, and the color is more intense than that of extracts of 8-mercaptoquinoline. This indicates that the water of crystallization is firmly bound in the 6-bromo-8-mercaptoquinoline, and the reagent goes into the organic solvent (at least partially) in the form of the intensely colored dihydrate.

6-Bromo-8-mercaptoquinoline dihydrate is converted at 89.5° to a blue liquid similar to anhydrous 8-mercaptoquinoline. It may be assumed that, as in the case of 8-mercaptoquinoline, melting of 6-bromo-8-mercaptoquinoline occurs with the loss of the water of crystallization and conversion to the liquid, anhydrous, blue 6-bromo-8-mercaptoquinoline. When heated in a capillary, the blue liquid condenses on the walls of the capillary in the form of blue drops which soon crystallized, forming completely colorless, acicular crystals. These crystals gradually (in the course of 30-50 minutes) added the water which had been split from the dihydrate, and were again converted to bright-red crystals of the dihydrate. We previously observed a similar phenomenon during the dehydration of 8-mercaptoquinoline dihydrate under vacuum. In this case, after some time in the evacuated desiccator, the partially dehydrated, red 8-mercaptoquinoline dihydrate was observed in the form of a white, solid mass, which, on further dehydration, was converted to a blue liquid. The white, intermediate product formed during the dehydration of 8-mercaptoquinoline is apparently unstable and is formed under strictly fixed conditions, since we did not observe it in further experiments. In the case of 6-bromo-8-mercaptoquinoline, the white intermediate product is stable, is formed readily, and can be isolated. The composition of this substance is not clear. It may be assumed that the product is the monohydrate in both cases.

As pointed out above, at 89.5° 6-bromo-8-mercaptoquinoline dihydrate is converted to a liquid, splitting off water of crystallization. Thus, 89.5° is not the melting point, but the decomposition temperature of the dihydrate. The removal of water of crystallization from 8-mercaptoquinoline takes place at 59°. The greater strength of the bonding of the water of crystallization in 6-bromo-8-mercaptoquinoline explains its significantly greater stability (as compared to 8-mercaptoquinoline) toward the action of atmospheric oxygen. 6-Bromo-8-mercaptoquinoline dihydrate was unchanged after standing open to the air for two months. In comparison, 8-mercaptoquinoline oxidized in a few days under the same conditions.

Preliminary experiments showed that, as a reagent of the type R—SH, 6-bromo-8-mercaptoquinoline interacts in aqueous solutions with cations formed from sulfides which are not hydrolyzed by water; water-insoluble inner-complex salts are formed, and these frequently impart an intense color to the organic solvents with which they are extracted. A more detailed study of the properties of these salts is under way at the present time.

SUMMARY

1. 6-Bromo-8-mercaptoquinoline, which has not been described in the literature, was synthesized; it separates from aqueous solutions in the form of the red, crystalline dihydrate. The dehydration of this substance was studied.

2. In aqueous solutions, 6-bromo-8-mercaptoquinoline forms, with the cation groups of hydrogen sulfide and ammonium sulfide, colored inner-complex salts which are insoluble in water and soluble in organic solvents.

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THE NUMBER OF OPTICAL STEREOISOMERS AND THEIR DISTRIBUTION WITH RESPECT TO THE DIFFERENT TYPES OF CONFIGURATION IN COMPOUNDS WITH CONTINUOUS SERIES OF ASYMMETRIC CENTERS IN AN UNBRANCHED CHAIN

L. A. Mai

The question of the number of optical stereoisomers and their distribution with respect to the different types of configuration is of great interest in the chemistry of sugars and other compounds with a continuous series of asymmetric centers. Moreover, up to the present, there has been no classification of such compounds by type of configuration of the chain of asymmetric centers, and the distribution of the stereoisomers with respect to the various types of configuration is unknown. Formulas for the calculation of the number of stereoisomers have been presented by Van't Hoff [1] and by E. Fischer [2] for simple cases of compounds with few asymmetric centers in an unbranched chain and by Senior [3] for certain more complex cases with a branched chain. A general method for calculating the number of optical and geometrical stereoisomers was developed by Branch and Hill [4].

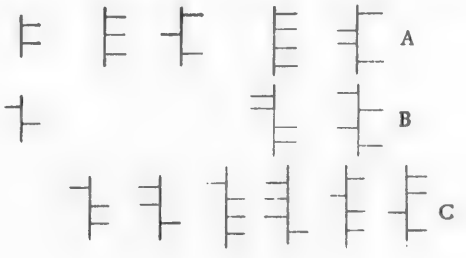
In the present communication we shall consider the distribution of optical stereoisomers with respect to the various configurational types in compounds having the structure $X(CHZ)_nY$, where X, Y and Z are groups which do not contain asymmetric centers. Sugars and their α,ω-derivatives are examples of compounds of this type. We divide compounds of this type into three groups according to the steric configuration of the chain of asymmetric centers (configurational symmetry of the chain) regardless of whether they have like or unlike terminal groups X and Y.

1) Symmetrical type – the molecule has a plane of symmetry; this type is possible for any (even or uneven) value of n (erythro-, xylo-, ribo-, allo-, gala-configuration) (A).

2) Antisymmetric ("quasi-centrosymmetric") type – rotation of one half of the molecule through 180° leads to a position of mirror symmetry with respect to the second half of the molecule; this type is possible only for an even number of carbon atoms n (threo-, manno-, ido-configuration) (B).

3) Unsymmetrical type – the molecule has no plane of symmetry, and also does not conform to the condition for an antisymmetric type; this type is possible with any value of n (starting with 3) (arabo-, lyco-, altro-, talo-, gluco-, gulo-configuration) (C).

As an example we may cite the polyoxymethylene chain (one enantiomorphous stereoisomer) of tetroses, pentoses and hexoses.



Compounds with like terminal groups, X and Y, we shall call homoterminal, while those with unlike terminal groups we shall call heteroterminal. The ratio of the number of, and the configurational interconnection of, homoterminal and heteroterminal stereoisomers having the same chain of asymmetric centers are characteristics of each of the above types of configuration. Each symmetric homoterminal compound corresponds to two enantiomorphous stereoisomeric (D,L) heteroterminal compounds, each antisymmetric homoterminal compound corresponds to one heteroterminal compound with the same steric configuration, and each unsymmetrical homoterminal compound corresponds to two heteroterminal diasteroisomers. In the sugar group, these relationships were established chiefly by the classic researches of E. Fischer and G. Kiliani, and, as is well known, constitute the basis of one of the most important routes for determining steric configuration, namely, oxidation-reduction conversion of aldoses into the corresponding sugar alcohols and α,ω-dicarboxylic acids.

1) On oxidation of one of the terminal groups, a symmetrical sugar alcohol gives an aldose racemate, and a dicarboxylic acid forms the monolactone racemate, for example, in the conversion cycle dulcitol – D,L-galactose – mucic acid – D,L-monolactone of mucic acid – D,L-galactonic acid – D,L-galactose – dulcitol.

2) On going from antisymmetric sugar alcohols to the corresponding aldose and α,ω-dicarboxylic acid, the configuration of the chain is retained; for example, D-mannitol – D-mannose – D-mannosaccharic acid – (dilactone of D-mannosaccharic acid) – D-mannitol.

3) An unsymmetrical sugar alcohol and α,ω-dicarboxylic acid correspond to two diastereoisomeric aldoses, monolactones, and aldonic acids; for example, D-sorbitol – D-glucose, L-glucose – D-glucosaccharic acid – 2 diastereoisomeric monolactones – D-gluconic acid, L-gluconic acid – D-glucose, L-glucose – D-sorbitol.

Formulas for calculating the number of optical stereoisomers can be derived as follows. If the molecule has n asymmetric centers (regions) (a, b, c . . . n) with the possibilities (possible number of stereoisomers) p_a, p_b, $p_c \cdots p_n$, then the total number of stereoisomers for the given molecule is

$$N = p_a \cdot p_b \cdot p_c \cdots p_n. \tag{1}$$

Since in the case of optical stereoisomers, each asymmetric center (region) has two possibilities ($p_a = p_b = \ldots = 2$),

$$N = 2^n. \tag{2}$$

This formula, however, holds only in the case of n structurally different asymmetric regions; i.e., it gives the number of heteroterminal stereoisomers. In case there are present structurally equivalent asymmetric regions (according to the conditions for configurational symmetry presented above), the number of stereoisomers is given by the formula

$$N = 2^{n-\nu}, \tag{3}$$

where ν is the number of equivalent asymmetric centers. According to the conditions of classification of configurational symmetry, for heteroterminal-symmetric compounds with an even value of n, $\nu = n/2$, with odd values of n, $\nu = (n-1)/2$, and for antisymmetric compounds, $\nu = n/2$. By the introduction of the trigonometric multipliers $\sin^2(\pi n/2)$ and $\cos^2(\pi n/2)$, we can express the total number of stereoisomers for even and odd values of n by equations for the number of symmetric (N_s) and antisymmetric (N_a) stereoisomers. The difference $N - N_s - N_a$ gives the number of unsymmetrical stereoisomers, N_u.

Owing to the possibility of inversion identity ("head-tail" rotation), the total number of homoterminal stereoisomers is less than the number of the corresponding heteroterminal compounds; for odd values of n

$$N' = \frac{2^n}{2} = 2^{n-1}, \tag{4}$$

and for even values of n, this number is increased by the number of antisymmetric stereoisomers for which inversion identity does not exist (for example, D- and L-mannosaccharic acids)

$$N' = \frac{2^n}{2} + \frac{2^{\frac{n}{2}}}{2} = \frac{2^n + 2^{\frac{n}{2}}}{2}. \tag{5}$$

For individual types of configurational symmetry (N_s', N_a'), the values of ν [Formula (3)] are obtained in the same manner as for heteroterminal compounds, from the classification conditions of symmetry. The number of unsymmetrical stereoisomers N_u is similarly obtained from the difference $N' - N_c' - N_a'$. All of the formulas presented below can also be derived by calculating the possibilities for a region and successively combining antisymmetric regions according to the general method of Branch and Hill [4].

Using a single function for any value of n instead of separate functions for even and odd values of n, the number of stereoisomers (without accounting for racemic, anomeric, and other forms) can be expressed by the following equations.

The Number of Stereoisomers and Their Distribution According to Type of Configuration for $X(CHZ)_nY$ Compounds

No. of asymmetric C atoms (n)	Heteroterminal compounds ($X \neq Y$)				Homoterminal compounds ($X = Y$)			
	symmetrical	antisymmetric	unsymmetrical	total	symmetrical	antisymmetric	unsymmetrical	total
1	(2)	0	0	2	1	0	0	1
2	2	2	0	4	1	2	0	3
3	4	0	4	8	2	0	2	4
4	4	4	8	16	2	4	4	10
5	8	0	24	32	4	0	12	16
6	8	8	48	64	*	8	24	36
7	16	0	112	128	8	0	56	64
8	16	16	224	256	8	16	112	136
9	32	0	480	512	16	0	240	256
10	32	32	960	1024	16	32	480	528

I. Heteroterminal Compounds

1) Total number of stereoisomers

$$N = 2^n. \tag{2}$$

2) Number of symmetrical stereoisomers

$$N_c = 2^{\frac{n+\sin^2\frac{\pi n}{2}}{2}}. \tag{6}$$

3) Number of antisymmetric stereoisomers

$$N_a = 2^{\frac{n}{2}} \cos^2\frac{\pi n}{2}. \tag{7}$$

4) Number of unsymmetrical stereoisomers

$$N_u = 2^n - 2^{\frac{n}{2}}\left(\cos^2\frac{\pi n}{2} + 2^{\frac{1}{2}\sin^2\frac{\pi n}{2}}\right). \tag{8}$$

II. Homoterminal Compounds

1) Total number of stereoisomers

$$N' = \frac{N}{2}\left(1 + \frac{1}{\sqrt{2^n}}\cos^2\frac{\pi n}{2}\right) = 2^{n-1} + 2^{\frac{n-2}{2}}\cos^2\frac{\pi n}{2}. \tag{9}$$

2) Number of symmetrical stereoisomers (they are all diastereoisomers)

$$N_c' = \frac{N_c}{2} = 2^{\frac{n+\sin^2\frac{\pi n}{2}-2}{2}}. \tag{10}$$

3) Number of antisymmetric stereoisomers

$$N_a' = N_a = 2^{\frac{n}{2}}\cos^2\frac{\pi n}{2}, \tag{11}$$

i.e., $2^{(n-2)/2}\cos^2(\pi n/2)$ are enantiomorphous pairs.

4) Number of unsymmetrical stereoisomers

$$N'_n = \frac{N_n}{2} = 2^{n-1} - 2^{\frac{n-2}{2}}\left(\cos^2\frac{\pi n}{2} + 2^{\frac{1}{2}}\sin^2\frac{\pi n}{2}\right). \quad (12)$$

In the Table are presented the numbers of possible stereoisomers for a given number of asymmetric carbon atoms up to 10, and also their distribution according to type of configuration.

SUMMARY

1. Classifications and characteristics of types of configuration (configurational symmetry) are given for compounds with continuous series of asymmetric centers in an unbranched chain.

2. Equations are given for calculating the number of optical stereoisomers of all three types; in place of different functions for even and uneven values of the variable (number of asymmetric centers), single functions are derived for any value of the variable, and these exhibit the oscillating character of the given dependence.

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REACTIONS OF PYRIDINIUM SALTS

II. INTERACTION OF CHLORO-2,4-DINITROPHENYLATES OF SUBSTITUTED PYRIDINE BASES WITH ANILINE

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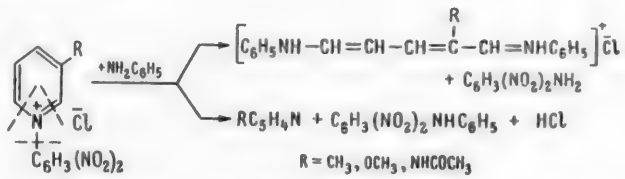
In spite of the long time that reactions resulting in the opening of the pyridine ring have been known, the effect of substituents in the pyridine ring on the course of this reaction has remained obscure up to the present. In connection with this, we have undertaken an investigation of the interaction of the chloro-2,4-dinitrophenylate of pyridine [N-(2,4-dinitrophenyl)pyridinium chloride] and its derivatives (cf. [1, 2]) with aromatic amines, particularly with aniline. It was found that this reaction can proceed in different directions depending on the nature of the substituents, its position in the pyridine ring, and the temperature conditions. When a weakly electropositive substituent (for example, CH_3, $NHCOCH_3$) is present in the β-position, cleavage of the pyridine ring proceeds at 0-15° (in ethyl alcohol medium), but the yield is less than in the case of unsubstituted pyridine. When alcoholic solutions of such chlorodinitrophenylates are heated with aniline, the formation of 2,4-dinitrodiphenylamine takes place along with ring cleavage. In the latter case, rupture of the $N-C_6H_3(NO_2)_2$ bond evidently proceeds under the action of the amine. Picrates of the corresponding pyridine bases were isolated from the reaction solutions of the individual experiments.

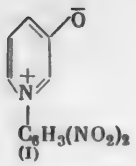


It should be pointed out that in the case of the chlorodinitrophenylate of β-picoline [N-(dinitrophenyl)picolinium chloride], the formation of phenyldinitrophenylamine also occurs at a temperature of +5°.

Pyridine chlorodinitrophenylate is almost quantitatively cleaved by aniline in alcoholic solution, both in the cold and on heating, with the formation of the hydrochloride of the dianil of glutaconic aldehyde [3]. The conclusion follows, therefore, that the pyridine ring is stabilized by the introduction of a weakly electropositive substituent (CH_3, OCH_3 and $NHCOCH_3$ groups) into the β-position. Since the introduction of these substituents leads only to partial stabilization of the ring (along with the phenyldinitrophenylamine, some cleavage products are formed), we undertook the task of determining the effect of substituents possessing clearly expressed basic properties, for example, the dimethylamino group.

It was found that the pyridine ring in the chlorodinitrophenylate of β-dimethylaminopyridine [N-dinitrophenyl-β-dimethylaminopyridinium chloride] is very stable toward the action of aniline. This compound does not react appreciably with aniline at 0-10°, while at 60-80°, only the extra-ring nitrogen-carbon bond is cleaved. The yield of phenyldinitrophenylamine in this reaction amounts to 85% after just a three-hour heating.

The chlorodinitrophenylates of β-amino- (cf. [4]) and β-hydroxypyridine react with aniline in a manner similar to that of β-dimethylaminopyridine chlorodinitrophenylate. In the case of the hydroxy compound, the stabilizing effect on the ring bonds is undoubtedly due to the formation of the betaine (I) (cf. [1, 2]).



(I)

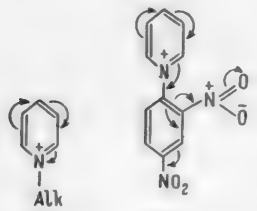
Thus, a further increase in the electropositive properties of a substituent in the β-position leads to a considerable strengthening of the ring carbon-nitrogen bonds in reactions with aromatic amines. In this case, only rupture of the extra-ring bond occurs.

A shift of a weakly electropositive substituent from the β- to the γ-position also leads to strengthening of the ring bonds. Thus, for example, in γ-acetamidopyridine chlorodinitrophenylate, in contrast to the β-derivative, the pyridine ring is cleaved neither in the cold nor by heating. In this case, only phenyldinitrophenylamine is formed (yield 11.5% after heating for three hours on a water bath). γ-Phenylaminopyridine chlorodinitrophenylate reacts in precisely the same way when heated with aniline, forming phenyldinitrophenylamine (yield 23% after heating for five hours on a water bath).

It is interesting that when an iodine atom, which possesses weakly electronegative properties, is introduced into the β-position of the pyridine ring, the stabilizing effect on the ring bonds completely disappears; β-iodopyridine chlorodinitrophenylate reacts with aniline in alcoholic solution with rupture of the ring bonds [5]. In this case, it was not possible to detect the formation of phenyldinitrophenylamine either in the cold or with heating.

On heating, the reaction of the chlorodinitrophenylates of γ-acetamido- and γ-phenylaminopyridine with aniline is accompanied by the formation of colored substances in addition to the phenyldinitrophenylamine. These same compounds are obtained when the reaction mixture is not heated. An investigation of these substances showed that they are molecular compounds. They will be described in more detail later.

Furthermore, the formation of phenyldinitrophenylamine (~2% of theoretical), in addition to products of ring cleavage, was also observed during the interaction of pyridine chlorodinitrophenylate with aniline in aqueous alcoholic solution, but not in alcoholic solution. Hence, it particularly follows that, in addition to other factors, the nature of the solvent has an effect on the course of the reaction.



(II) (III)

It may be assumed that in the pyridinium cation (owing to the high mobility of the π-electrons of the ring), the positive charge is associated not only with the ring nitrogen atom, but also partially with the carbon atoms of the pyridine ring. Many transformations of pyridinium and quinolinium salts can be explained if it is assumed that the positive charge of their cations is delocalized, chiefly at the expense of the α- and γ-carbons of the ring (see Formula II). Thus, for example, the ready transition of N-alkyl-pyridinium and N-alkylquinolinium salts to pseudobases during their interaction with hydroxyl ions is apparently connected with the presence of a partial positive charge on the α-carbons of the cation.

When the alkyl group in N-alkylpyridinium salts is replaced by an electronegative radical, there must be a considerable shift of the π-electron density of the pyridine ring in the direction of this radical (cf., for example, Formula III). As a consequence of this, there should be a strengthening of the positive charges at the α- and α'-carbons (owing to which an attack by a nucleophilic reagent is facilitated) and a weakening of the ring C–N bonds in reactions with bases. This conclusion is in agreement with the known experimental material: alkylpyridinium and arylpyridinium halides do not react with aromatic amines in contrast to, for example, 2,4-dinitrophenylpyridinium salts (cf. [6]).

Generally speaking, the introduction of a nitro group into the benzene ring of an N-arylpyridinium salt (in a position ortho or para to the pyridine nitrogen) must lead to a weakening, not only of the ring, but also of the extra-ring C–N bonds. Experiment shows that in the case of an unsubstituted pyridine ring, the ring C–N bonds are the most vulnerable, since the attack of a nucleophilic reagent (an amine) is directed first of all at these bonds. In the pyridine chlorodinitrophenylates having electronegative substituents in the β- or the γ-positions, the π-electron density in the pyridine ring must be increased under the influence of these substituents (in comparison with derivatives which are not substituted in the ring). For this reason, an attack by an amine is directed predominantly at the extra-ring nitrogen-carbon bond rather than at the ring bonds.

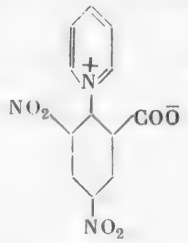
From this point of view, the introduction into the pyridine ring of strongly electropositive substituents should entirely, or almost entirely, prevent the ring-cleavage reaction. As already pointed out above, experiments have confirmed this proposition. The existence of a shift of π-electrons toward the ring nitrogen atom with the introduction of electropositive substituents into the pyridine ring can, in certain cases, be confirmed indirectly – by a comparison of the experimental dipole moments with those calculated on the basis of additivity for the original

bases. Thus, for example, for γ-phenylaminopyridine the experimental value of the dipole moment (3.64 D) differs considerably from the calculated value (2.72 D [7]). Such an increase can be explained only by a shift of electrons from the phenylamino group to the ring nitrogen.

The presence of color in γ-phenylaminopyridine chlorodinitrophenylate indicates a partial transition of the phenylamino group in this compound to the tetravalent state.

The conversions of chlorodinitrophenylates of β- and γ-substituted pyridines under the influence of aniline, which were the subject of our studies, constitute an example of the general reaction in which quaternary salts of pyridine, quinoline, and isoquinoline are cleaved by the action of water, alcohols, aromatic amines, phenols, and other substances. In all of these cases, rupture of the extra-ring bond proceeds especially readily if the hetero ring has little tendency toward rupture (for example, in quinoline) and if the heterocyclic nitrogen atom is joined to an electronegative radical. Thus, the presence of an electronegative radical leads, in general, not only to a weakening of the ring C−N bonds, but also to a weakening of the extra-ring N−C.

A considerable number of reactions of this nature are described in the literature. Thus, during the interaction of isoquinoline chloro-2,4-dinitrophenylate in alcoholic solution with aniline or with p-toluidine, 2,4-dinitro-α-naphthylamine and 2,4-dinitro-α-naphthyl-p-tolylamine are formed [8]. Kabachnik and Zitser found that 6,7-dimethoxyisoquinoline chloro-2,4-dinitrophenylate reacts, in alcoholic solution, with these same amines in a similar manner [9]. It is interesting that 4-pyridylpyridinium dichloride reacts with aniline to form the hydrochloride of glutaconic aldehyde dianil [glutacondianil] and γ-phenylaminopyridine [10]. Consequently, in this case, both reactions − ring cleavage and splitting off of the extra-ring radical − proceed at commensurate rates. Under the action of potassium phenolate in phenol solution, 4-pyridylpyridinium dichloride is cleaved with the formation of γ-phenoxypyridine [11]. β-Nitro-γ-pyridylpyridinium chloride is readily cleaved by water with the formation of β-nitro-γ-hydroxypyridine [12]. On heating the betaine (IV) with methyl or ethyl alcohol, rupture of the extra-ring bond occurs, and the corresponding esters of dinitrosalicylic acid and pyridine are obtained [13].


(IV)

It is interesting that in quaternary salts of aromatic amines with an electronegative radical at the nitrogen atom, rupture of the N−C bond accompanied by splitting out of alkyl halide very frequently proceeds spontaneously at ordinary temperatures. Thus, for example, the product of the addition of phosgene to trimethylamine decomposes with the evolution of methyl chloride at ordinary temperatures [14]. In precisely the same manner, the interaction of 2,4-dinitrochlorobenzene with trimethylamine readily yields 2,4-dinitrodimethylaniline with the elimination of methyl chloride [15]. The chlorodinitrophenylate of trimethylamine [dinitrophenyltrimethylammonium chloride] is so unstable that it cannot be isolated from the reaction mixture. Undoubtedly, von Braun cleavage of amines by means of cyanogen bromide also belongs to this series of reactions.

An interesting question arises as to the mechanism of the rupture of ring and extra-ring C−N bonds in pyridinium salts, particularly in the chlorodinitrophenylates of substituted pyridines, under the influence of aromatic amines and other substances. It is very probable that cleavage of these bonds proceeds simultaneously with the formation of the covalent bond between the α-carbon of the pyridine ring or the corresponding carbon of the benzene ring and the nitrogen atom in the amine molecule (cf. [16]). However, with respect to cleavage of the extra-ring bonds, another mechanism is possible. Undoubtedly, pyridine chlorodinitrophenylate and related compounds possess the dual character of quaternary ammonium salts and molecular compounds (cf., for example,[17]). However, the phenomenon of dissociation in solutions is a characteristic of many molecular compounds. As a result of an investigation of the kinetics of the reaction between picryl chloride and pyridine in ethyl alcohol, Hodges [18] came to the conclusion that the following equilibrium is established in alcohol solution:

$$C_5H_5N + ClC_6H_2(NO_2)_3 \rightleftarrows C_5H_5\overset{+}{N}C_6H_2(NO_2)_3Cl$$

It is possible that a similar equilibrium is established in alcoholic solutions of chlorodinitrophenylates of substituted pyridines.

If a chlorodinitrophenylate is insignificantly dissociated in alcoholic solution at low temperatures, and if the substituent in the pyridine ring does not possess a highly stabilizing effect on the ring bonds, then it is possible for the ring-cleavage reaction to proceed preferentially in the presence of an aromatic amine. Naturally,

on heating an alcoholic solution of the chlorodinitrophenylate, dissociation will increase. In this case, when an electropositive substituent is present on the pyridine ring, the formation of phenyldinitrophenylamine (or its derivative) can emerge as the chief reaction. As already pointed out, when a weakly electropositive substituent is present in the β-position of the pyridine ring, cleavage of the extra-ring bond in the corresponding chlorodinitrophenylate proceeds (in alcoholic solutions) as the predominant reaction at elevated temperatures. Moreover, in contrast to reactions involving cleavage of the ring C—N bonds (under the influence of aromatic amines) in these same compounds, rupture of the extra-ring bond proceeds significantly more slowly. In addition, it is known that the formation of dinitro-α-naphthylphenylamine or dinitro-α-naphthyl-p-tolylamine during the action of the appropriate amines on isoquinoline chlorodinitronaphthylate [N-dinitronaphthylisoquinolinium chloride] also proceeds appreciably more slowly than the usual reaction of cleavage of the pyridine ring* (cf. [8]). All of the above statements support the assumption of the dissociation of chlorodinitrophenylates of substituted pyridines into the components during their interaction with aromatic amines in alcoholic solutions.

EXPERIMENTAL

Interaction of pyridine chloro-2,4-dinitrophenylate and aniline on heating. To a hot solution of 2.8 g of pyridine chloro-2,4-dinitrophenylate in 30 ml of 30% ethyl alcohol was added 1.86 g of aniline, and the mixture was refluxed for four hours. When the liquid was gradually cooled, a heterogeneous precipitate — yellow plates (which constituted the major part of the precipitate) and orange crystals — separated. The crystals were filtered and dried (weight, 1.65 g; m.p. 171°), and were then treated with hot toluene (twice with 5-ml portions). The insoluble portion (1.33 g) consisted of yellow plates with m.p. 179-180°, and they did not cause depression of the melting point when mixed with known 2,4-dinitroaniline. Yellow crystals of 2,4-dinitroaniline (0.06 g; m.p. 177-178°) precipitated from the cooled toluene extract. Thus, the over-all yield of dinitroaniline was 1.39 g (76%). The toluene solution was evaporated to dryness, and the residue was recrystallized from aqueous alcohol. This procedure yielded reddish-orange needles (0.02 g) with an m.p. of 156-157°, which did not cause depression of the melting point when mixed with known phenyl-2,4-dinitrophenylamine. The aqueous-alcoholic filtrate from the reaction mixture was evaporated. The residue (a viscous, dark-red liquid with the odor of aniline) was washed with toluene and dissolved in ethyl alcohol (8 ml). The picrate was precipitated from the solution. The weight of picrate was 2.94 g (76.6% calculated as the pyridine N-phenylpicrate). The picrate was in the form of fine, light-yellow needles, m.p. 122-123° (from ethyl alcohol) (123-124° [19]).

Reaction of β-picoline chloro-2,4-dinitrophenylate with aniline. a) At 5°. 0.89 g of β-picoline chloro-2,4-dinitrophenylate and 0.56 g of aniline were dissolved in 7 ml of ethyl alcohol. The dark-red liquid was allowed to stand, protected from the light, for 70 hours at 5°. The precipitated red crystals were washed on the filter with ethyl alcohol (1 ml), dried, and heated on a water bath with dry acetone (4 ml). The acetone solution was filtered, and the crystals were washed on the filter with dry acetone (2 ml). The yield was 0.27 g (29.6% calculated as the hydrochloride of α-methylglutaconic aldehyde dianil). The m.p. was 137-138° (with decomposition). (The m.p. was unchanged after recrystallization from ethyl alcohol.) The fine, bright-red needles, which were soluble in methyl and ethyl alcohol and insoluble in water, acetone, and ether, contained water of crystallization.

Found % H_2O 1.97; N 9.04, 9.01. $C_{18}H_{19}N_2Cl \cdot 1/3H_2O$. Calculated % H_2O 1.97; N 9.20.

The acetone filtrate was evaporated. The orange-yellow residue (weight, 0.10 g) was treated with hot toluene (12 ml). The insoluble residue was composed of orange-yellow crystals (weight, 0.04 g; m.p. 158-167°). After recrystallization from ethyl alcohol, there was obtained 0.03 g of yellow prisms with an m.p. of 178°; a mixture of these prisms with 2,4-dinitroaniline showed no depression of the melting point.

The toluene solution was agitated with 2% sulfuric acid, and was then washed with water and dried over sodium sulfate. The toluene was distilled under vacuum. The residue (0.05 g; m.p. 127-132°) was recrystallized from ethyl alcohol (2.5 ml). The resulting orange needles (0.025 g), with an m.p. of 152-153°, caused no depression of the melting point when mixed with phenyl-2,4-dinitrophenylamine.

The solution from the reaction mixture (strong odor of β-picoline!), after separation of the crystals, was evaporated at 15-20° under vacuum. The residue was washed in several portions with hot, dry acetone (28 ml). The rose crystals (0.48 g; m.p. 188-189°) did not dissolve; shaking an aqueous solution of the crystals with activated carbon, evaporation of the solution, and recrystallization of the residue from anhydrous alcohol gave a colorless substance with an m.p. of 200-201°; a mixture of this material with β-picoline chlorodinitrophenylate

*Should be isoquinoline ring. See T. Zincke and F. Krollpfeifer, C.A., 9, 1462 (1915).

showed no depression of the melting point. The acetone solution was evaporated, and the residue (0.59 g) was ground, in several portions, with warm toluene (30 ml). The toluene solution was washed with 2% sulfuric acid and then with water; the solution was then dried over sodium sulfate, and the toluene was distilled under vacuum to a volume of 8-10 ml. The precipitated yellow crystals were filtered; the weight was 0.05 g; m.p. 177°; a mixture of this material with 2,4-dinitroaniline showed no depression of the melting point. The filtrate was evaporated; the residue was composed of orange-yellow crystals (0.09 g; m.p. 128-137°). Recrystallization from ethyl alcohol (4.5 ml) gave orange needles (0.04 g) with an m.p. of 152-153°; after a second recrystallization, the m.p. was 155°. A mixture of this material with phenyl-2,4-dinitrophenylamine showed no depression of the melting point. The over-all yield of crystallized phenyl-2,4-dinitrophenylamine was 0.065 g (8.3%).

b) With heating. 0.89 g of β-picoline chloro-2,4-dinitrophenylate and 0.56 g of aniline were dissolved in 6 ml of ethyl alcohol and refluxed on a water bath (4.5 hours). The mixture of yellow prisms and orange needles which precipitated from the cooled, dark-red solution was washed on the filter with ethyl alcohol (1 ml). The weight was 0.53 g. The coarse, yellow prisms were separated mechanically (0.08 g); m.p. 166-168°. Recrystallization from 2 ml of ethyl alcohol gave 0.06 g of a substance with an m.p. of 176-178°. A mixture of this material with 2,4-dinitroaniline showed no depression of the melting point. The major part of the precipitate (0.45 g; m.p. 124-125°), which remained after separation of the yellow prisms, was recrystallized twice from anhydrous alcohol. 0.19 g of long, reddish-orange needles with an m.p. of 156-157° was obtained; a mixture of this material with phenyl-2,4-dinitrophenylamine showed no depression of the melting point. The mother liquor was evaporated, and the residue was washed with warm toluene (20 ml). The insoluble part (yellow crystals, 0.16 g, m.p. 152-165°) was recrystallized from alcohol. There was obtained 0.12 g of a substance with an m.p. of 179-180°; a mixture of this material with 2,4-dinitroaniline showed no depression of the melting point. Thus, the over-all yield of crystallized dinitroaniline was 0.18 g (33.3%).

The toluene solution was washed with dilute hydrochloric acid and then with water, and was dried over sodium sulfate. The toluene was distilled under vacuum. The residue (yellowish-orange crystals, 0.09 g, m.p. 130-138°) was recrystallized from anhydrous alcohol (1.5 ml). The yield was 0.05 g. The orange needles, m.p. 154-156°, caused no depression of the melting point when mixed with known phenyl-2,4-dinitrophenylamine. The over-all yield of crystallized phenyldinitrophenylamine was 0.24 g (30.7%).

Interaction of β-acetamidopyridine chloro-2,4-dinitrophenylate [N-2,4-dinitrophenyl-β-acetamidopyridinium chloride] with aniline. a) At 10-15°. Aniline (1.86 g) was added to a solution of β-acetamidopyridine chloro-2,4-dinitrophenylate (1.69 g) in ethyl alcohol (70 ml), and the mixture was allowed to stand at 10-15° for 24 hours. Long, thin, red crytals, which were agglomerated in groups, were separated from the dark-red liquid. They were washed on the filter with ethyl alcohol; the weight was 1.05 g, and the m.p. was 140° (with decomposition). After 24 hours, an additional 0.26 g of red needles with an m.p. of 136° (with decomposition) was separated from the filtrate from the reaction mixture. The over-all yield of the hydrochloride of α-acetamidoglutaconic aldehyde dianil was 1.31 g (76.5%). After the crystals were recrystallized from methanol, the melting point increased to 143° (with decomposition). The substance contained water of crystallization (determined by drying at 40° under vacuum).

Found % H_2O 4.52; N 11.83, 11.86. $C_{19}H_{20}ON_3Cl \cdot H_2O$. Calculated % H_2O 5.01; N 11.69.

We were unable to detect phenyl-2,4-dinitrophenylamine in the filtrate.

b) With heating. 1.0 g of β-acetylamidopyridine chloro-2,4-dinitrophenylate and 0.56 g of aniline were heated in a flask, fitted with a reflux condenser, in 10 ml of ethyl alcohol on a boiling water bath (four hours). From the cooled, brown-red solution, after it had stood (20 hours), was isolated a mixture (0.40 g) of brownish-red prisms and light-reddish-orange needles. The latter were separated mechanically. The weight was 0.02 g; m.p. 138-145° (after recrystallization of the material from ethyl alcohol, the m.p. increased to 156°); a mixture of this substance with phenyl-2,4-dinitrophenylamine showed no depression of the melting point. After recrystallization of the major part of the precipitate (0.38 g) from ethyl alcohol, yellow prisms of 2,4-dinitroaniline (0.27 g) were obtained; m.p. 179-180°. From the filtrate from the reaction mixture, after further standing, was isolated an additional 0.06 g of 2,4-dinitroaniline (m.p. 172-176°). The over-all yield of dinitroaniline was 0.44 g (81.3%).

Picric acid (0.68 g in 10 ml of alcohol) was added to the alcoholic filtrate after removal of the phenyl-2,4-dinitrophenylamine and 2,4-dinitroaniline. The weight of the precipitated picrate was 0.9 g (68.2% calculated as the N-phenylpicrate of β-acetamidopyridine); m.p. 142-143°. Recrystallization from alcohol gave 0.69 g of of fine, light-yellow prisms with an m.p. of 148-149°.

Found %: N 15.96. $C_{19}H_{15}O_8N_5$. Calculated %: N 15.86.

Reaction of β-methoxypyridine 2,4-dinitrophenylate with aniline. 0.12 g of β-methoxypyridine chloro-2,4-dinitrophenylate [N-2,4-dinitrophenyl-β-methoxypyridinium chloride] and 0.07 g of aniline were heated in 1 ml of alcohol on a water bath for 1.5 hours. Orange needles of phenyl-2,4-dinitrophenylamine, 0.38 g (38.3%), separated from the cooled reddish-brown solution. The m.p., 151-152°, increased to 156° after recrystallization of the crystals from ethyl alcohol. Dry ether was added to the filtrate. The small amount of tarry precipitate was filtered, and picric acid (0.1 g in 20 ml of ether) was added to the solution. The weight of picrate was 0.03 g (23%); m.p. 128-129° (after recrystallization from ethyl alcohol); a mixture of this material with known β-methoxypyridine picrate showed no depression of the melting point.

Reaction of β-dimethylaminopyridine chloro-2,4-dinitrophenylate with aniline. A mixture of 0.65 g of β-dimethylaminopyridine chloro-2,4-dinitrophenylate [N-2,4-dinitrophenyl-β-dimethylaminopyridinium chloride], and 0.37 g of aniline was dissolved in 4 ml of anhydrous alcohol and heated for three hours on a water bath at 60-80°. A voluminous precipitate of phenyl-2,4-dinitrophenylamine (dark-orange needles) separated from the cooled orange-brown solution. The crystals were washed on the filter with ethyl alcohol; weight, 0.4 g; m.p., 147-149°. Dark-orange needles crystallized from the filtrate on long standing; weight, 0.04 g; m.p., 146-148°. Thus, the over-all yield of phenyl-2,4-dinitrophenylamine was 0.44 g (84.9%). After recrystallization from methyl alcohol, the reddish-orange needles melted at 156-157° (weight, 0.3 g); a mixture of the crystals with known phenyl-2,4-dinitrophenylamine showed no depression of the melting point. Dry ether (150 ml) was added to the filtrate remaining after separation of the phenyl-2,4-dinitrophenylamine. The reddish-brown oil which separated was mixed with an 8% solution of sodium bicarbonate (50 ml). The dark-yellow solution was extracted with ether, and the picrate was precipitated from the ether extract; yield, 0.37 g (52.7%); m.p., 172-173° (after 2-fold recrystallization from ethyl alcohol, 174-175°); a mixture of the yellow prisms with known β-dimethylaminopyridine picrate showed no depression of the melting point.

Found %: N 19.77. $C_{19}H_{13}O_7N_5$. Calculated %: N 19.95.

Interaction of β-hydroxypyridine chloro-2,4-dinitrophenylate with aniline. a) With heating. 0.30 g of β-hydroxypyridine chloro-2,4-dinitrophenylate [2,4-dinitrophenyl-β-hydroxypyridinium chloride] and 0.19 g of aniline were heated in 10 ml of ethyl alcohol on a boiling-water bath for three hours. After 24 hours, the reddish-brown liquid was filtered from the small amount of dark precipitate, and the filtrate was evaporated under vacuum. The brown crystals were extracted with hot toluene, the solvent was then distilled under vacuum, and the residue was crystallized from ethyl alcohol, 0.06 g (23.1%) of reddish-orange needles of phenyl-2,4-dinitrophenylamine, m.p. 156°, was obtained. A mixture of this material with known phenyl-2,4-dinitrophenylamine melted at the same temperature.

b) At room temperature. 0.25 g of β-hydroxypyridine chloro-2,4-dinitrophenylate and 0.16 g of aniline were mixed with 7 ml of ethyl alcohol and allowed to stand at room temperature for nine months. A small amount of tarry crystals separated from the dark-orange solution. The solvent was evaporated under vacuum, and the residue was extracted with toluene (35 ml). The toluene extract was washed with 3% hydrochloric acid and then with water, and was dried with anhydrous sodium sulfate. After distillation of the toluene under vacuum, the residue was recrystallized from alcohol. The resulting reddish-orange needles, m.p. 156°, weight 0.07 g (32.2%), caused no depression of the melting point when mixed with known phenyl-2,4-dinitrophenylamine.

Interaction of γ-acetamidopyridine chloro-2,4-dinitrophenylate with aniline when heated. A solution of 0.34 g of the chloro-2,4-dinitrophenylate of γ-acetamidopyridine [γ-acetamido-N-2,4-dinitrophenylpyridinium chloride] and 0.18 g of aniline in 10 ml of ethyl alcohol was heated to boiling in a flask fitted with a reflux condenser on a boiling-water bath (three hours). The coarse, heavy, dark-red prisms and fine, reddish-orange needles which separated from the cooled solution stratified on the bottom of the vessel with the prisms on the bottom. The needles, being lighter, became suspended when the solution was agitated, and were filtered separately. The weight was 0.03 g (11.5%) and the m.p. 154°; recrystallized from ethyl alcohol gave 0.015 g of crystals with m.p. 156°. A mixture of these crystals with known phenyl-2,4-dinitrophenylamine melted at the same temperature. The dark-red prisms, 0.20 g, m.p. 218°, were then filtered, and were identified as a molecular compound of γ-acetoamidopyridine chloro-2,4-dinitrophenylate with aniline.

Reaction of γ-phenylaminopyridine chloro-2,4-dinitrophenylate with aniline when heated. 0.37 g of γ-phenylaminopyridine chloro-2,4-dinitrophenylate [2,4-dinitrophenyl-γ-phenylaminopyridinium chloride] and

0.18 g of aniline in 5 ml of ethyl alcohol were heated on a boiling-water bath for five hours. Orange needles separated from the cooled reddish-orange solution after the introduction of a small seed crystal of phenyldinitrophenylamine; weight, 0.06 g (23.1%); m.p., 155°; a mixture of the crystals with known phenyl-2,4-dinitrophenylamine showed no depression of the melting point. Red prisms, identified as a molecular compound of γ-phenylaminopyridine chloro-2,4-dinitrophenylate with aniline, crystallized from the cooled filtrate; weight, 0.19 g; m.p., 210°.

Interaction of β-iodopyridine chloro-2,4-dinitrophenylate with aniline. To a solution of 0.2 g of β-iodopyridine chloro-2,4-dinitrophenylate [N-2,4-dinitrophenyl-β-iodopyridinium chloride] in 8 ml of ethyl alcohol was added 0.09 g of aniline, and the mixture was refluxed on a water bath for three hours. The solution was then evaporated to dryness under vacuum. The residue was washed with hot toluene (7 ml) and crystallized from alcohol. The resulting yellow prisms weighed 0.07 g (77.8%) and melted at 179° after 2-fold recrystallization from alcohol); a mixture of this material with known 2,4-dinitroaniline melted at the same temperature. Phenyl-2,4-dinitrophenylamine was not found in either the toluene extract or the alcohol filtrates.

SUMMARY

1. The reaction of the chloro-2,4-dinitrophenylates of pyridine and its derivatives with aniline was investigated. It was found that this reaction proceeds in different directions depending on the nature of the substituent, its position on the pyridine ring, and the temperature conditions.

2. When electropositive substituents are present on the pyridine ring, the ring N—C bonds in the corresponding chlorodinitrophenylates are stabilized with respect to the action of the base. In this case, rupture of the extra-ring bond occurs, either alone or together with the ring bonds.

3. A shift of the electropositive substituent in the chlorodinitrophenylate of the pyridine base from the β-position to the γ-position increases the stabilizing effect of the substituent on the ring N—C bonds in the reaction with aniline.

4. The investigated conversions of the chloro-2,4-dinitrophenylates of β- and γ-substituted pyridines constitute an example of the general reaction of cleavage of quaternary salts of pyridine, quinoline, and isoquinoline by the action of water, alcohols, aromatic amines, phenols, etc. Rupture of the extra-ring N—C bond proceeds especially easily if the heterocyclic nitrogen atom is bonded to an electronegative radical.

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ON SOME PROPERTIES OF ENOL ACETATES

III. PREPARATION OF FURAN AND PYRAN DERIVATIVES FROM BROMO-SUBSTITUTED ENOL ACETATES

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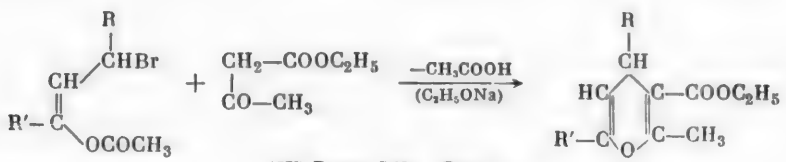
In a preceding communication [1], we described the preparation, in good yield, of 2-methyl-3-carbethoxy-4,5,6,7-tetrahydrocumarone by the condensation of the bromo-substituted enol acetate of cyclohexanone with sodioacetoacetic ester.

In the present work, we synthesized 2-ethoxy-3-carbethoxy-4,5,6,7-tetrahydrocoumarone, in 65% yield, by the condensation of this same bromo-substituted enol acetate with sodiomalonic ester.

Then, by condensing the bromo-substituted enol acetates (I), (II) and (III), having the general formula $R-CHBr-CH=C(OCOCH_3)-R'$,* with sodioacetoacetic ester, we were able to carry out the synthesis of a series of compounds of the pyran group, (IV), (V) and (VI), the formation of which is expressed by the following general scheme:



(IV) $R = n\text{-}C_4H_9$, $R' = H$,
(V) $R = CH_3$, $R' = CH_3$,
(VI) $R = C_6H_5$, $R' = CH_3$.

The bromo-substituted enol acetates (I), (II) and (III) were easily prepared (in yields of from 38 to 57%) by the action of N-bromosuccinimide on the enol acetates of, respectively, enanthole [heptanal], methyl propyl ketone, and benzylacetone. The condensations with sodioacetoacetic ester were carried out under approximately the same conditions that were described in the preceding communication [1]. 2-Methyl-4-butyl-3-carbethoxypyran (IV) was prepared from (I) with a yield of 69%, (II) gave 2,4,6-trimethyl-3-carbethoxypyran (V) in 63.4% yield, and 2,6-dimethyl-4-phenyl-3-carbethoxypyran (VI) was synthesized from (III) with a yield of 61.5%.

Some of the properties of these pyran derivatives were investigated. It was established that when heated with an alcoholic solution of potassium hydroxide, (IV) undergoes hydrolysis with the formation of 2-methyl-4-butyl-3-pyrancarboxylic acid (VII). When (V) and (VI) are treated similarly, along with hydrolysis, decarboxylation occurs, which leads to the formation of 2,4,6-trimethylpyran (VIII) and 2,6-dimethyl-4-phenylpyran (IX), respectively.**

During the interaction of (VII), (VIII) and (IX) with 2,4-dinitrophenylhydrazine sulfate, cleavage of the

*The reactions were carried out using compounds in which: (I) $R = n\text{-}C_4H_9$ and $R' = H$; (II) $R = CH_3$ and $R' = CH_3$; (III) $R = C_6H_5$ and $R' = CH_3$.

**Up to the present time, the simplest substituted pyrans have not been prepared [2]. Of the aryl-substituted pyrans, only 2,4,4,6-tetraphenyl-γ-pyran is known [3].

pyran ring (and in the case of (VII), decarboxylation also) occurred, which resulted in the formation of the bis-2,4-dinitrophenylhydrazones of the corresponding 1,5-dicarbonyl compounds: 3-butyl-5-hexanone-1-al, 4-methyl-2,6-heptanedione, and 4-phenyl-2,6-heptanedione, respectively.

EXPERIMENTAL

1. Preparation of 2-Ethoxy-3-carbethoxy-4,5,6,7-tetrahydrocoumarone

160 ml of anhydrous alcohol was charged to a three-necked flask fitted with a stirrer, a reflux condenser with calcium chloride tube, and a dropping funnel, and 6.9 g of metallic sodium was gradually added. The solution was cooled to room temperature, and, with stirring, 64 g of freshly distilled malonic ester was gradually added followed by 65.7 g of 3-bromo-2-acetoxy-1-cyclohexene.* The reaction mixture was refluxed on a water bath for two hours. The liquid was cooled, suction filtered to remove the precipitated sodium bromide, and the alcohol was distilled under the vacuum of an aspirator (while heated on a water bath). A small amount of water was added to the residue, and the mixture was extracted with ether. The ether extract was dried with sodium sulfate, the ether was distilled, and the residue was distilled under vacuum. After distillation of the unreacted acetoacetic ester, the 2-ethoxy-3-carbethoxy-4,5,6,7-tetrahydrocoumarone was distilled at 120-125° (4 mm). The yield was 46.5 g (65%).

Found %: C 65.23; H 7.23. Saponification number 455.8. $C_{13}H_{18}O_4$. Calculated %: C 65.53; H 7.61. Saponification number 471.

2. Preparation of the Enol Acetate of Benzylacetone

To a solution of 74.1 g of benzylacetone in 153.2 g of acetic anhydride was added 25 drops of concentrated H_2SO_4, and the reaction mixture was allowed to stand at room temperature for 20 days.** The unreacted acetic anhydride was then decomposed by agitation with water, solid sodium carbonate was added to an alkaline reaction, and the reaction product was extracted with ether. The ether extract was washed with a 15% solution of sodium carbonate to complete removal of residual acid, then with water, and dried over sodium sulfate. The ether was distilled under aspirator vacuum, and the residue was distilled under vacuum. The benzylacetone enol acetate distilled at 112-114° (2 mm). The yield was 29.8 g (31.3%).

Found %: C 75.61; H 7.69. Saponification number 309.8; bromine number 81.5. $C_{12}H_{14}O_2$. Calculated %: C 75.76; H 7.42. Saponification number 294.2; bromine number 83.9.

3. Allylic Bromination of the Enol Acetates of Enanthole,*** Methyl Propyl Ketone,**** and Benzylacetone

The bromination was carried out with N-bromosuccinimide by the method described by us for cyclohexanone enol acetate [4]. The yields of bromination products were, respectively, 57, 48.5 and 37.9%.

3-Bromo-1-acetoxy-1-heptane (I) was a colorless liquid with a b.p. of 63-65° (3 mm). The product was not stable toward storage, and it rapidly darkened on standing. This caused inaccuracy in the determination of the bromine content.

Found %: Br 27.12, 27.35. $C_9H_{15}O_2Br$. Calculated %: Br 33.14.

4-Bromo-2-acetoxy-2-pentene (II) was a colorless liquid with a b.p. of 45-47° (3 mm). In contrast to the preceding product, it was stable on storage.

Found %: Br 38.23. $C_7H_{11}O_2Br$. Calculated %: Br 38.59.

1-Bromo-3-acetoxy-1-phenyl-2-butene (III) was a colorless liquid with a b.p. of 122-124° (2 mm).

*The 3-bromo-2-acetoxy-1-cyclohexane was prepared by bromination of the enol acetate of cyclohexanone with N-bromosuccinimide [4].

**The yield of the enol acetate decreased when the reaction time was less.

***The enanthole acetate was prepared by heating enanthole with acetic anhydride in the presence of sodium acetate [5].

****The methyl propyl ketone enol acetate was prepared by the interaction of methyl propyl ketone with acetic anhydride in the presence of sulfuric acid [6].

Found %: Br 28.40. $C_{12}H_{13}O_2Br$. Calculated %: Br 29.69.

4. Synthesis of 2-Methyl-4-butyl-3-pyrancarboxylic Acid (VII)

A. Preparation of 2-methyl-4-butyl-3-carbethoxypyran (IV). 40 g of anhydrous alcohol was charged to a three-necked flask fitted with a stirrer, a reflux condenser with calcium chloride tube, and a dropping funnel, and 2.3 g of sodium was gradually added. The solution was then cooled to room temperature, and 26 g of acetoacetic ester was added, with cooling and stirring, followed by 23.5 g of 3-bromo-1-acetoxy-1-heptene. Even in the cold, a precipitate of sodium bromide was formed. The reaction mixture was heated for an hour at a water-bath temperature of 60°. After the liquid was cool, it was suction filtered from the precipitated sodium bromide, and the alcohol was distilled under aspirator vacuum. A small amount of water was added to the residue, and the mixture was extracted with ether. The ether solution was dried with sodium sulfate, and the ether was distilled; the residue was distilled under vacuum. After distillation of the unreacted acetoacetic ester, the ethyl ester of 2-methyl-4-butyl-3-pyrancarboxylic acid was distilled at 118-120° (4 mm); the amount was 15.4 g (69%). The 2-methyl-4-butyl-3-carbethoxypyran was a light-yellow liquid with a distinctive odor.

Found %: C 69.62, 69.27; H 9.32, 9.13. Saponification number 259.6. $C_{13}H_{20}O_3$. Calculated %: C 69.61; H 8.98. Saponification number 250.1.

B. Hydrolysis of the 2-methyl-4-butyl-3-carbethoxypyran (IV) was carried out by heating it (4.5 g) with 80 ml of an 0.5-N alcoholic solution of potassium hydroxide at the boiling point for two hours. Carbon dioxide was passed into the reaction mixture to remove the excess potassium hydroxide, the liquid was suction filtered from the resulting K_2CO_3 precipitate, and the precipitate was washed with alcohol. The alcohol was distilled from the filtrate under aspirator vacuum. The solid residue (the potassium salt of VII) was dissolved in a small amount of water, the solution was acidified with a 2-N solution of hydrochloric acid, and the resulting acid (VII) was extracted with ether. The ether solution was dried with sodium sulfate, the ether was distilled, and the residue was distilled under vacuum. 2.3 g of (VII) was obtained with a b.p. of 145-147° (4 mm).

Found %: C 67.19; H 8.54. Acid number 262.3. $C_{11}H_{16}O_3$. Calculated %: C 67.32; H 8.22. Acid number 285.6.

Interaction of acid (VII) with 2,4-dinitrophenylhydrazine. 10 ml of anhydrous alcohol was added to 1 g of 2,4-dinitrophenylhydrazine which had been dissolved, with gentle heating, in 2 ml of concentrated H_2SO_4, and immediately a solution of 0.5 g of (VII) in anhydrous alcohol was added. After some time, a precipitate of 3-butyl-5-cyclohexanone-1-al bis-2,4-dinitrophenylhydrazone formed, and this was separated and recrystallized several times from a mixture of alcohol and ethyl acetate. The red crystals melted at 165° (with decomposition).

Found %: N 20.75, 20.82. $C_{22}H_{26}O_8N_8$. Calculated %: N 21.08.

5. Synthesis of 2,4,6-Trimethylpyran (VIII)

A. Preparation of 2,4,6-trimethyl-3-carbethoxypyran (V). The following quantities of starting materials were used: 130 ml of anhydrous alcohol, 5.75 g of sodium, 65 g of acetoacetic ester, and 51.7 g of the bromo-substituted enol acetate of methyl propyl ketone. The condensation was carried out under the same conditions used in the preparation of (IV) with the exception that the heating was continued for three hours at reflux temperature. The precipitate of sodium bromide began to form only on heating. Treatment of the reaction mixture and separation and purification of the resulting product was carried out in the manner used in the preceding case. 31 g (63.4%) of 2,4,6-trimethyl-3-carbethoxypyran was obtained in the form of a slightly yellowish liquid with a b.p. of 102-103° (2 mm).

Found %: C 67.09; H 7.95. Saponification number 289.1. $C_{11}H_{16}O_3$. Calculated %: C 67.32; H 8.22. Saponification number 285.3.

B. Preparation of 2,4,6-trimethylpyran (VIII). 9.8 g of 2,4,6-trimethyl-3-carbethoxypyran was heated to boiling over a period of two hours with 200 ml of an 0.5-N alcoholic solution of potassium hydroxide; during this, the formation of a precipitate of K_2CO_3 was observed on the walls of the flask. Carbon dioxide was passed into the reaction mixture to remove the excess potassium hydroxide, and the resulting K_2CO_3 precipitate was separated and washed with alcohol. The alcohol was distilled from the filtrate, the residue was dissolved in water, and the reaction product was extracted with ether. The extract was dried with sodium sulfate, the ether was distilled, and the residue was distilled under vacuum.

3.82 g (61.5%) of 2,4,6-trimethylpyran was obtained. It was a colorless liquid with a characteristic odor and a b.p. of 70-72° (2 mm).

Found %: C 77.12, 76.98; H 9.65, 9.42. $C_8H_{12}O$. Calculated %: C 77.37; H 9.74.

The interaction of (VIII) with 2,4-dinitrophenylhydrazine under the conditions described in the preceding experiment gave 4-methyl-2,6-heptanedione bis-2,4-dinitrophenylhydrazone – red crystals with an m.p. of 116° (with decomposition) (from a mixture of alcohol and ethyl acetate).

Found %: N 21.86. $C_{20}H_{22}O_8N_8$. Calculated %: N 22.23.

6. Synthesis of 2,6-Dimethyl-4-phenylpyran (IX)

A. Preparation of 2,6-dimethyl-4-phenyl-3-carbethoxypyran (VI). The following amounts of starting materials were used: 65 ml of anhydrous alcohol, 2.3 g of sodium, 26 g of acetoacetic ester, and 26.9 g of the bromo-substituted enol acetate of benzylacetone. The condensation and treatment of the reaction mixture were carried out as described for the preceding experiment. 13.5 g (52.2%) of 2,6-dimethyl-4-phenyl-3-carbethoxypyran was obtained in the form of a yellowish liquid with a b.p. of 148-151° (2 mm).

Found %: C 74.14; H 6.90. Saponification number 202.5. $C_{16}H_{18}O_3$. Calculated %: C 74.39; H 7.02. Saponification number 216.3.

B. Preparation of 2,6-dimethyl-4-phenylpyran (IX). 12.9 g of (VI) and 200 ml of an 0.5-N alcoholic solution of potassium hydroxide were used. The reaction and treatment of the product were carried out as in the preceding experiment. 5.2 g (55.6%) of 2,6-dimethyl-4-phenylpyran was obtained. It was a light-yellow liquid with a b.p. of 135-136° (3 mm).

Found %: C 83.62; H 7.71. $C_{13}H_{14}O$. Calculated %: C 83.83; H 7.57.

Interaction of (IX) with 2,4-dinitrophenylhydrazine gave 4-phenyl-2,6-heptanedione 2,4-dinitrophenylhydrazone. The brown crystals melted at 138° (with decomposition) (from a mixture of alcohol and ethyl acetate).

Found %: N 19.63. $C_{25}H_{24}O_8N_8$. Calculated %: N 19.86.

SUMMARY

1. The condensation of 3-bromo-2-acetoxy-1-cyclohexene with sodiomalonic ester gave 2-ethoxy-3-carbethoxy-4,5,6,7-tetrahydrocoumarone; this product has not previously been described in the literature.

2. It was shown that condensation of brominated enol acetates of the type $R-CHBr-CH=C(OCOCH_3)R'$ with sodioacetoacetic ester leads to the formation of the corresponding pyran derivatives. The following compounds were obtained: 2-methyl-4-butyl-3-carbethoxypyran, 2,4,6-trimethyl-3-carbethoxypyran, and 2,6-dimethyl-4-phenyl-3-carbethoxypyran.

3. It was established that when heated with alcoholic alkali, 2-methyl-4-butyl-3-carbethoxypyran is converted to 2-methyl-4-butyl-3-pyrancarboxylic acid. When heated with alcoholic alkali under the same conditions, 2,4,6-trimethyl-3-carbethoxypyran and 2,6-dimethyl-4-phenyl-3-carbethoxypyran undergo hydrolysis and also decarboxylation with the formation of 2,4,6-trimethylpyran and 2,6-dimethyl-4-phenylpyran, respectively. None of these substituted pyrans have been described in the literature.

4. The bromo-substituted enol acetates of enanthole, methyl propyl ketone, and benzylacetone were prepared for the first time by bromination of the corresponding aldehyde (enanthole) and methyl ketones (methyl propyl ketone and benzylacetone) with N-bromosuccinimide.

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ON THE SYNTHESIS AND STRUCTURE OF THE o-SULFOBENZOYL DICHLORIDES

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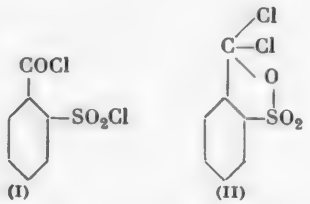
The o-sulfobenzoyl dichlorides have found widespread application in organic synthesis, particularly in the synthesis of sulfophthalein indicators [1-6].

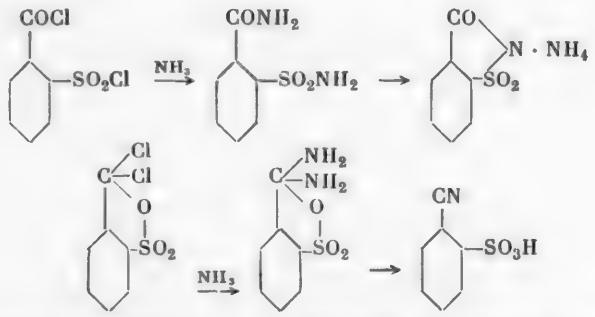
The o-sulfobenzoyl dichlorides have been isolated in two isomeric forms – the symmetrical and lactone structures [7-9].



(I) (II)

One of the dichlorides has an m.p. of 40°, decomposes under the action of ammonia [7, 10], and withstands heating under vacuum to 183° [11]. The second has an m.p. of 79°, is stable to the action of ammonia at a temperature of about 20°, and decomposes during vacuum distillation at 20-30 mm [7] and at 15 mm [11] to o-chlorobenzoyl chloride and sulfur dioxide. An attempt to convert one isomer into the other failed [7]. The two dichlorides form an eutectic mixture which melts at 21° [13] or 21.5° [8].

The literature contains more than one opinion on the question of which dichloride has the symmetrical and which the lactone structure. According to the data of certain investigators [7, 8], isomer (I) has the m.p. of 79°, while (II) has the 40° m.p.. The authors came to this conclusion on the basis of the reactions occurring during the action of ammonia on (I) and (II).



However, in more recent investigations [9], it was shown that the action of ammonia on symmetrical dichlorides can also lead to the formation of CN-groups, provided that the chlorocarbonyl groups are ortho to each other. By comparing the absorption spectra of o-sulfobenzoic acid and its dichlorides with the spectra of o-toluenesulfonic acid and its chloride, these same investigators came to the conclusion that the dichloride with

an m.p. of 40° has the symmetrical structure, while the one with the m.p. of 79° has the lactone structure.

According to information in the literature, an eutectic mixture of isomeric dichlorides is obtained by the action of phosphorus pentachloride on the potassium acid salt [7, 12], the dipotassium salt [11, 13], and the ammonium acid salt [6, 11] of o-sulfobenzoic acid.

The interaction of dipotassium o-sulfobenzoate with phosphoryl chloride at 130° (under pressure) leads to the dichloride with an m.p. of 40° [7].

The dichloride with an m.p. of 79° has not been obtained by direct synthesis; it can be isolated from the mixture of isomers after decomposition with ammonia of the dichloride with an m.p. of 40° [7, 10]. The use of thionyl chloride leads not to the dichloride, but to the anhydride of o-sulfobenzoic acid [14, 15].

The aim of the present investigation was the development of a convenient method for the preparation of the o-sulfobenzoyl dichlorides in the form of a mixture of the two isomers.

The interaction of phosphorus pentachloride with the alkali metal salts of o-sulfobenzoic acid can be carried out by heating the reagents on a water bath [11] or by triturating them in a mortar [7]. The latter method has only preparative significance.

Heating a mixture of the dipotassium salt of o-sulfobenzoic acid and phosphorus pentachloride on a steam bath did not give positive results, even at 120-130°.

Carrying out the reaction in the presence of phosphoryl chloride by adding the dipotassium sulfobenzoate to a mixture of phosphorus pentachloride and a small amount of phosphoryl chloride was found to be very effective. The reaction proceeded very vigorously with the liberation of heat. Adding the dipotassium salt and the phosphorus pentachloride portion-wise and separately, maintained the reaction mass as a liquid and made continuous stirring possible over the entire course of the synthesis.

As recommended by some investigators [7], the reaction mixture was washed several times with ice water to remove the potassium chloride formed during the reaction (decomposition of the phosphoryl chloride occurred simultaneously). However, after being washed with water, the dichlorides became unstable at room temperature, apparently owing to insignificant amounts of residual water. During drying, even with such mild drying agents as sodium sulfate, evolution of heat by the oil and evolution of hydrogen chloride and sulfur dioxide were observed. Therefore, this method of treating the reaction mixture had to be abandoned.

Almost quantitative separation of the potassium chloride was accomplished by extraction of the dichlorides from the reaction mass with benzene or chloroform. The solution of dichlorides was then distilled at 15-20 mm absolute pressure. Contrary to statements in the literature [7, 11], there was practically no decomposition of the dichloride with an m.p. of 79° during the distillation, and we repeatedly separated it from the eutectic mixture of the two isomers.

The isomeric dichlorides obtained by the above method did not contain chlorine in the ring, showing the absence of o-chlorobenzoyl chloride which is formed in the case of the decomposition of the isomer with an m.p. of 79°. Hydrolysis of the dichlorides with water gave a quantitative yield of pure o-sulfobenzoic acid, in which there was no chloride, which also indicated that there was no o-chlorobenzoyl chloride in the dichloride mixture.

These experimental data indicate that the dichloride with an m.p. of 79° is thermally stable during distillation at 15-20 mm (b.p. 165-176°).

With equimolar amounts of dipotassium o-sulfobenzoate and phosphorus pentachloride, the yield of dichlorides varied in the range of 50-60%; it increased to 74-75% when the amount of phosphorus pentachloride was increased to 15% excess with respect to the theoretical amount.

In view of the uncertainty and contradictions in the information concerning which of the o-sulfobenzoyl dichlorides should be assigned the symmetrical and which the lactone structure, it was of interest to compare the half-wave potentials ($E_{1/2}$) of these dichlorides with those of the dichlorides of o-phthalic acid. The latter also forms two dichlorides having symmetrical and lactone structures; the structure and physical constants for each of them have been established [16].

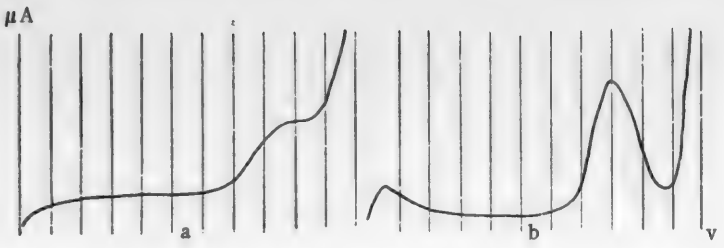


Fig. 1. o-Sulfobenzoyl dichloride with an m.p. of 40°: a) ordinary wave (S = 1/15); b) derivative wave (S = 1/1).

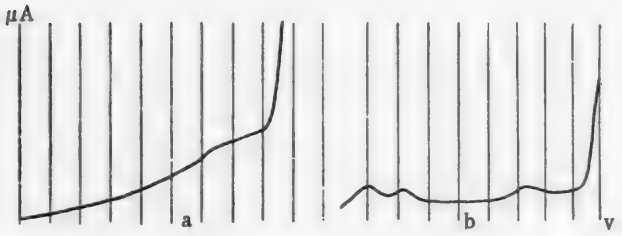


Fig. 2. o-Sulfobenzoyl dichloride with an m.p. of 79°: a) ordinary wave (S = 1/30); b) derivative wave (S = 1/1).

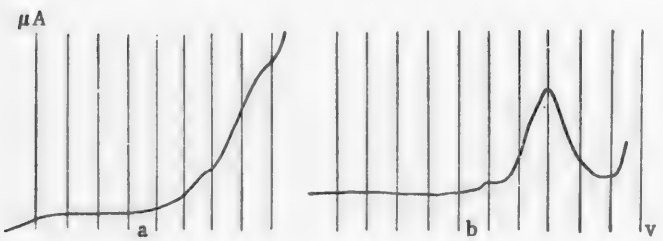


Fig. 3. o-Phthaloyl dichloride (symmetrical structure): a) ordinary wave (S = 1/15); b) derivative wave (S = 1/5).

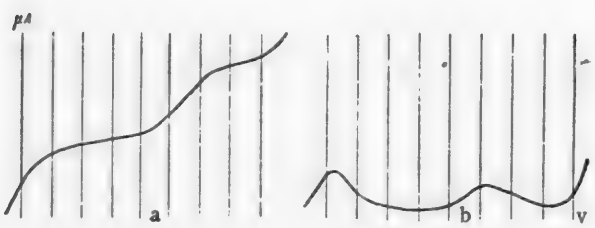
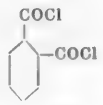
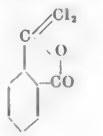


Fig. 4. o-Phthaloyl dichloride (lactone structure): a) ordinary wave (S = 1/5); b) derivative wave (S = 1/5).

The individual dichlorides of o-sulfobenzoic acid and o-phthalic acid were synthesized in the pure form by methods described in the literature [7, 10, 16].

The results of the polarographic measurements are presented in the Table and in Figs. 1-4.

Half-Wave Potentials of the Dichlorides of o-Sulfobenzoic and o-Phthalic Acids (with respect to a saturated calomel electrode)

Dichloride	Melting point	Structural formula	$E_{1/2}$ of the polarographic wave (v)	
			ordinary	derivative*
o-Sulfobenzoyl dichloride	40°	—	—1.56	—1.60
o-Sulfobenzoyl dichloride	79	—	—1.20	—1.26
Symmetrical o-phthaloyl dichloride	16		—1.58	—1.60
o-Phthaloyl dichloride with lactone structure	80		—1.20	—1.22

*Recording of the derivative waves was necessary owing to the lack of clarity in the ordinary waves of the o-sulfobenzoyl dichloride, with an m.p. of 79°, and of the o-phthaloyl dichloride, with an m.p. of 16°.

It may be seen from the Table and the figures that the values of the half-wave potentials are in good agreement: 1) for symmetrical o-phthaloyl dichloride and the o-sulfobenzoyl dichloride with an m.p. of 40° and 2) for the o-phthaloyl dichloride with a lactone structure and the o-sulfobenzoyl dichloride with an m.p. of 79°.

These numerical values of $E_{1/2}$ permit the conclusion that the o-sulfobenzoyl dichloride with an m.p. of 40° has the symmetrical structure, while the one with an m.p. of 79° has the lactone structure.

These results confirm the data of Scheiber and Knothe [9].

EXPERIMENTAL

Synthesis of the mixture of isomeric dichlorides. Into a three-necked flask fitted with a stirrer and a reflux condenser, the end of which was connected to a calcium chloride tube, was introduced 51 g of phosphoryl chloride, and 70 g of carefully ground phosphorus pentachloride was added with stirring. 15 g of dipotassium o-sulfobenzoate was then added; the mixture rapidly liquefied, and another 74 g of phosphorus pentachloride was then added. Exothermic heat raised the temperature to 45-50°. 68.5 g of the dipotassium salt was added portion-wise over a period of an hour at a temperature of 80-90°. The mixture was heated to boiling (115-117°) and stirred for three hours; it was then cooled to 50°, 75 ml of benzene or chloroform was added, the mixture was stirred for 5-10 minutes, and cooled to 20°. The potassium chloride was filtered. A large part of the benzene and phosphoryl chloride was first distilled at atmospheric pressure, and the remainder of the benzene and phosphoryl chloride was distilled at 20-25 mm; the dichlorides came over at 165-170°. The yield was 52-54 g (72.5-75.3%).

Found %: Cl (in side chain) 29.5-29.8; Cl (total) 29.5-29.8. $C_7H_4O_3SCl_2$. Calculated %: Cl (in side chain) 29.66.

The Cl in the side chain was determined after hydrolysis of the dichloride with a 1.0-N solution of NaOH; Cl in the ring was determined by the Stepanov method, but ethyl alcohol was substituted for butyl.

The mixture of isomeric dichlorides was a colorless, oily liquid, from which a large quantity of crystals separated on standing. Hydrolysis of the dichlorides with water gave a quantitative yield of o-sulfobenzoic acid with an m.p. of 67-68° (literature value, 68-69° [17], 70° [18]).

Preparation of the dichloride with an m.p. of 79°. The distilled mixture of isomeric dichlorides (20 g) was dissolved in 20 ml of chloroform. The solution was cooled to 3-5°, and, over a period of 15 minutes, a 25% solution of ammonia was added to a weakly alkaline reaction (phenolphthalein). The excess ammonia was neutralized with hydrochloric acid (congo indicator). The chloroform layer was separated, dried with sodium sulfate, and treated with activated carbon. The chloroform was distilled at 80-100 mm. The residue crystallized in the flask. The yield was 2 g. M.p. 72.7-73.5° (literature value, 75.9° [8], 79° [7]). After several washings with petroleum ether, the m.p. was 77-78°.

Preparation of the dichloride with an m.p. of 40°. The distilled mixture of isomeric dichlorides (20 g) was allowed to stand for several days at a temperature of about 20°. The precipitated crystals were filtered and washed with petroleum ether. M.p. 38.0-39.0°.

Measurement of the half-wave potentials ($E_{1/2}$). Measurement of the half-wave potentials was carried out with a Heyrovsky-type micropolarograph with a dropping mercury electrode having forced interruption of the drops (with a period of 0.4 seconds). A saturated calomel electrode served as the anode. The solutions investigated polarographically were 0.001 M with respect to the dichloride and 0.25 M with respect to lithium chloride; the solvent was 50% alcohol. The maxima were suppressed with methyl red. The air was purged from the solutions by passing hydrogen through them for 15 minutes prior to recording the curve. The derivative curves were taken with a Vogel and Riha circuit incorporated into the polarograph circuit.

SUMMARY

1. A method satisfactory for technical use was developed for the preparation of the mixture of isomeric o-sulfobenzoyl dichlorides in yields of 72-75% of theoretical.

2. The reports in the literature that the dichloride with an m.p. of 79° is thermally unstable when distilled at a pressure of 15 mm were not confirmed. Distillation gave a mixture of the isomeric dichlorides.

3. A comparison of the half-wave potentials of the o-sulfobenzoyl dichlorides with those of the o-phthaloyl dichlorides permitted the conclusion that the o-sulfobenzoyl dichloride with an m.p. of 40° has the symmetrical structure, and the one with an m.p. of 79° has the lactone structure.

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THE PREPARATION OF Δ^{23}-3-KETO-24,24-DIPHENYLCHOLENE

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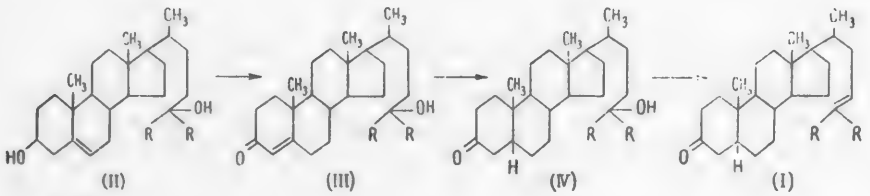
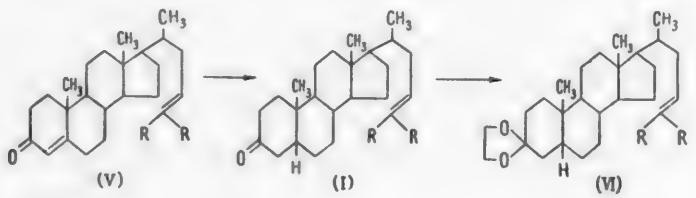
Δ^{23}-3-Keto-24,24-diphenylcholene (I) is of interest as a starting material for the synthesis of pregnane-3,20-dione from Δ^{5}-3β-hydroxycholenic acid. It was prepared from Δ^{5}-3β,24-dihydroxy-24,24-diphenylcholene (II) according to the scheme



R = C_6H_5

Δ^{5}-3β,24-Dihydroxy-24,24-diphenylcholene (II) was subjected to Oppenauer oxidation [1, 2] with cyclohexanone in the presence of aluminum isopropoxide. The substance, m.p. 136-137°, separated from the reaction mixture by appropriate treatment and recrystallization from methyl alcohol was, on the basis of the analytical data, an adduct of Δ^{4}-3-keto-24-hydroxy-24,24-diphenylcholene (III) with 0.5 molecule of methyl alcohol. The reduction of (III) was carried out in pyridine solution at room temperature and in the presence of palladium on calcium carbonate (2% Pd), since it is well known that the use of palladium on carbon or other carriers for the hydrogenation of Δ^{4}-3-ketosteroids leads to the formation of saturated 3-ketones of the normal series [3, 4]. From this reaction, we obtained a ketone with an m.p. of 181.5-182.5°, namely, 3-keto-24,hydroxy-24,24-diphenylcholane (IV); this ketone has not been described in the literature. Dehydration of this ketone by refluxing in glacial acetic acid [5] gave a previously unknown ketone (I) with an m.p. of 150-152°.

We were also able to prepare ketone (I) by a simpler method from $\Delta^{4,23}$-3-keto-24,24-diphenylcholadiene (V) by catalytic hydrogenation.



R = C_6H_5

During reduction of the substance (V) with palladium on calcium carbonate (2% Pd), 1 mole of hydrogen was absorbed, and a 91% yield of a substance with an m.p. of 150.5-152° was obtained; this was identified as our previously prepared (I).

Thus, under the hydrogenation conditions used, only one of the double bonds in (V), in the 4,5-position, was saturated. By refluxing, in an apparatus with a Dean and Stark head, a benzene solution of ketone (I) with excess ethylene glycol in the presence of a small amount of p-toluenesulfonic acid we obtained Δ^{23}-3-keto-24,24-diphenylcholene-3-ethylene ketal (VI) with an m.p. of 140.5-141.5°.

A study of conditions for the conversion of (VI) to ketone (I) showed that the best results are obtained when the ketal is refluxed for a considerable length of time in acetone solution with the addition of p-toluenesulfonic acid [6]; the reaction does not go to completion when (VI) is refluxed in aqueous acetic acid.

EXPERIMENTAL

Preparation of Δ^4-3-keto-24-hydroxy-24,24-diphenylcholene (III) containing 0.5 molecule of methyl alcohol. 3 g of Δ^5-3β,24-dihydroxy-24,24-diphenylcholene (II; m.p. 168-170°) and 85 ml of toluene were placed in a flask fitted with a thermometer, a stirrer, and a straight condenser. The mixture was heated to boiling, 15 ml of toluene was distilled, and then 2.4 ml of a 37% solution of aluminum isopropoxide in toluene was rapidly added, followed by another 8 ml of toluene. 10 ml of toluene was distilled, 14.32 g of cyclohexanone in 15 ml of toluene was added, and the reaction mixture was heated for 27 minutes; the heating was controlled so that the toluene distilled slowly. The reaction mixture was cooled, and a solution of 5.16 g of Seignette's salt [potassium sodium tartrate] in 5.5 ml of water was added. The aqueous layer was separated and extracted with toluene. The toluene solutions were combined and concentrated under vacuum at 35-40°, and the residual toluene was distilled at 40-60° and 1 mm. A yellow, oily substance remained, which crystallized when triturated with methyl alcohol. Recrystallization from methyl alcohol gave 2.17 g (70.4%) of a substance with an m.p. of 134-135.5°. A second recrystallization and drying of the crystals under vacuum at 70° increased the m.p. to 136-137°; $[\alpha]_D^{20}$ +59.2° (2% in chloroform). The substance was readily soluble in acetone, chloroform, and benzene, and difficultly soluble in alcohol.

Found %: C 83.21; H 8.92. $C_{36}H_{46}O_2 \cdot \frac{1}{2}CH_4O$. Calculated %: C 83.22; H 9.18.

Preparation of 3-keto-24-hydroxy-24,24-diphenylcholane (IV). The reduction of Δ^4-3-keto-24-hydroxy-24,24-diphenylcholene (2.7 g) was carried out in 12 ml of pyridine in the presence of 1.68 g of palladium on calcium carbonate (2.08% Pd). Over a period of three hours, 1 mole of hydrogen was absorbed, and the hydrogenation was then discontinued. The pyridine solution was poured into cold water and neutralized with hydrochloric acid; the hydrogenation product was extracted with chloroform. The chloroform solution was washed with dilute solutions of hydrochloric acid and sodium bicarbonate and then with water. The chloroform was distilled under vacuum, and the residue was washed with methyl alcohol. 2.54 g (96.6%) of a substance with an m.p. of 180-181.5° was obtained. Recrystallization from acetone and drying of the crystals at 100° under vacuum increased the m.p. to 181.5-182.5°; $[\alpha]_D^{20}$ +26.9° (2% in chloroform). The substance was readily soluble in benzene and chloroform and sparingly soluble in alcohol and ether.

Found %: C 84.35; H 9.15. $C_{36}H_{48}O_2$. Calculated %: C 84.32; H 9.43.

Preparation of Δ^{23}-3-keto-24,24-diphenylcholene (I) from 3-keto-24,24-diphenylcholane (IV). 0.5 g of (IV) was refluxed for 3.5 hours with 4 ml of glacial acetic acid. On cooling of the reaction mixture, a crystalline precipitate formed; this was filtered, washed with methyl alcohol, and dried. 0.43 g (89.2%) of a substance with an m.p. of 149.5-151° was obtained. Recrystallization of the crystals from a mixture of alcohol and acetone increased the m.p. to 150-152°; $[\alpha]_D^{20}$ +55.8° (2% in chloroform). The substance was readily soluble in ether, chloroform and benzene, soluble in acetone, and sparingly soluble in alcohol.

Found %: C 87.47; H 9.28. $C_{36}H_{46}O$. Calculated %: C 87.39; H 9.37.

Preparation of Δ^{23}-3-keto-24,24-diphenylcholene (I) from $\Delta^{4,23}$-3-keto-24,24-diphenylcholadiene (V). 10 g of $\Delta^{4,23}$-3-keto-24,24-diphenylcholadiene (m.p. 138-139°) in 50 ml of dry pyridine was reduced in the presence of 6 g of palladium on calcium carbonate (2.08% Pd). The absorption of hydrogen (1 mole) ceased after 8.5 hours. The catalyst was filtered and washed with a small amount of pyridine; the pyridine solution was poured, with stirring, into cold water, and a dilute solution of hydrochloric acid was added until the solution was acid, as shown by congo indicator. The substance separated first in the form of an oil, which rapidly crystallized; it wss extracted with ether. The ether extract was washed with dilute solutions of hydrochloric acid and sodium bicarbonate and then with water. It was dried with sodium sulfate. The ether was distilled under vacuum, and the residue was recrystallized from a mixture of 250 ml of alcohol and 100 ml of acetone. 8.26 g of a substance with an m.p. of 150.5-152° was obtained. An additional 0.88 g of the substance, m.p. 150-152°, was isolated from the filtrate. The total yield was 9.14 g (91%). A mixture of this material with a sample of the Δ^{23}-3-keto-24,24-diphenylcholene (I) prepared previously, showed no depression of the melting point.

Preparation of Δ^{23}-3-keto-24,24-diphenylcholene-3-ethylene ketal (VI). 12 g of Δ^{23}-3-keto-24,24-diphenylcholene, 12 ml of ethylene glycol, 360 ml of benzene, and 0.5 g of p-toluenesulfonic acid were refluxed for eight hours in an apparatus with a Dean and Stark head; water was separated during the reaction. The reaction mixture was cooled, a solution of potassium hydroxide in methyl alcohol was added, and the mixture was agitated with water. Ether was added, since separation of the layers was poor. The ether-benzene layer was washed three times with water, dried with anhydrous sodium sulfate, and the solvents were distilled under vacuum. The residue was recrystallized from 300 ml of acetone. 12.14 g (92.8%) of the ketal was obtained; m.p. 140.5-141.5°, $[\alpha]_D^{20}$ +52.2° (2% in chloroform). An additional 0.3 g of the substance, m.p. 139-140.5°, was isolated from the filtrate. The total yield was 12.44 g (95.1%). The substance was soluble in chloroform, benzene, and ether and sparingly soluble in alcohol and acetone.

Found %: C 84.67; H 9.37. $C_{39}H_{50}O_2$. Calculated %: C 84.71; H 9.35.

Conversion of ketal (VI) to ketone (I). a) 2 g of ketal (VI) was dissolved in 100 ml of dry acetone; 0.1 g of p-toluenesulfonic acid was added, and the mixture was refluxed for 14 hours. The solution was concentrated under vacuum to half its volume, 50 ml of water was added, and the resulting precipitate was filtered, washed with water to a neutral reaction, and dried under vacuum at 60°. Recrystallization from 60 ml of a mixture of alcohol and acetone (2.5 : 1) gave 1.55 g (84.4%) of a substance with an m.p. of 149-150°. A second recrystallization increased the m.p. to 150-152°. The first filtrate was evaporated to dryness under vacuum. The residue was again treated with acetone in pyridine in the presence of p-toluenesulfonic acid, as described above. An additional 0.11 g of the material, m.p. 149-150°, was obtained. The total yield was 1.66 g (90.4%).

b) 0.3 g of ketal (VI), 6 ml of glacial acetic acid, and 2 ml of water were refluxed for 25 minutes with stirring. 4 ml of glacial acetic acid was added, and refluxing was continued for another 25 minutes. The mixture was cooled, and the precipitate was filtered, washed with water to a neutral reaction, and dried. 0.27 g of a substance with an m.p. of 120-145° was obtained.

SUMMARY

Δ^{23}-3-Keto-24,24-diphenylcholene, which has not previously been described in the literature, was prepared by two methods: from Δ^5-3β,24-dihydroxy-24,24-diphenylcholene and from $\Delta^{4,23}$-3-keto-24,24-diphenylcholadiene.

Δ^{23}-3-Keto-24,24-diphenylcholene-3-ethylene ketal was also prepared. Conditions for its conversion to the 3-ketone were determined.

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THE PREPARATION OF PREGNANE-3,20-DIONE FROM Δ^{23}-3-KETO-24,24-DIPHENYLCHOLENE-3-ETHYLENE KETAL

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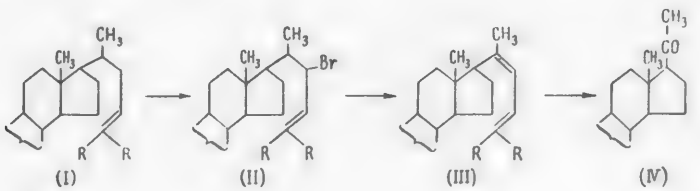
In the course of work on the synthesis of pregnane-3,20-dione, we investigated the bromination with N-bromosuccinimide of Δ^{23}-3-keto-24,24-diphenylcholene-3-ethylene ketal [1] and the dehydrobromination of the resulting 22-bromide.

In 1942, Ziegler and co-workers [2] showed that during the action of N-bromosuccinimide on unsaturated compounds, bromination occurs alpha to the double bond. Later, this reaction found widespread application, and, in particular, has been used in the chemistry of steroids for the conversion of compounds containing the Δ^{23}-24,24-diphenylcholene group (I) through the 22-bromide (II) and $\Delta^{20,23}$-choladiene (III) to the corresponding 20-ketosteroids (IV) according to the scheme:



(I) (II) (III) (IV)

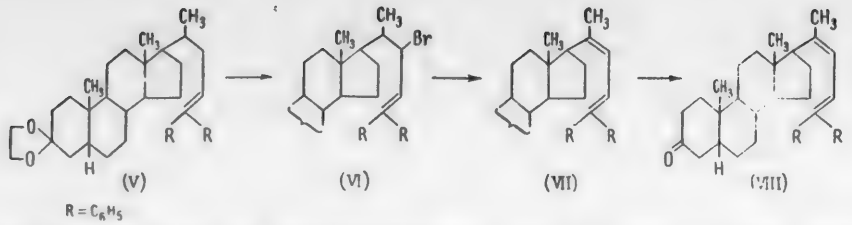
R = C_6H_5

The literature has repeatedly contained reports of the synthesis of various 20-ketosteroids from Δ^5-3β-hydroxycholenic acid [3, 4], 3β-hydroxyallocholanic acid [5], lithocholic acid [5], and desoxycholic acid [6, 7] by methods in which the last stages were carried out by the above scheme. However, the yields of (III) obtained from (I) for various compounds of this series, and sometimes for the same compound, varied considerably. For example, according to the data of Meystre and co-workers [6], the conversion of Δ^{23}-3α,12α-diacetoxy-24,24-diphenylcholene to $\Delta^{20,23}$-choladiene proceeds with a yield of 82%, while Casanova, Shoppee and Summers [7] indicated that considerable difficulty is encountered in carrying out this reaction. The authors reported that after discussing the reaction conditions with Wettstein, they were able to obtain what they considered satisfactory yields of choladiene (23.7-40.6%* in five experiments and 75% in one experiment under the same conditions). In connection with this, a study of the conversions (I) → (II) and (II) → (III) appeared to be of definite interest.

The present communication presents the results obtained during the bromination with N-bromosuccinimide of Δ^{23}-3-keto-24,24-diphenylcholene-3-ethylene ketal (V) and the subsequent conversion of the bromide (VI) to the previously undescribed $\Delta^{20,23}$-3-keto-24,24-diphenylcholadiene-3-ethylene ketal (VII) and $\Delta^{20,23}$-3-keto-24,24-diphenylcholadiene (VIII). The latter was oxidized with chromium trioxide to pregnane-3,20-dione.

The work was begun with a study of the dehydrobromination reaction. For this purpose, ketal (V) was brominated by the method common for analogous compounds — by refluxing in carbon tetrachloride with N-bromosuccinimide under illumination. After separation of the succinimide, the resulting bromide, without isolation, was further converted to choladiene. According to the literature, elimination of hydrogen bromide from C_{22}

*The amount of material isolated from the filtrates in these experiments was not reported.



bromides is accomplished by refluxing in carbon tetrachloride [3, 6, 7], in a mixture of carbon tetrachloride and glacial acetic acid [5], and in dimethylaniline [3, 4, 5] and also by heating with pyridine [8].

According to our observations, when dehydrobromination of (VI) is carried out in dimethylaniline (by refluxing for ten minutes), considerable tarring of the reaction products occurs. Therefore, this method was abandoned. When a solution of (VI) in carbon tetrachloride was refluxed (6.5 hours), the resulting compound contained 6% bromine (which corresponds to 46% of the monobromide of the ketal). A more detailed study of the hydrobromination reaction showed that the elimination of hydrogen bromide has already begun during the bromination process (four minutes after the beginning of the reaction). During the subsequent refluxing of the reaction mixture in carbon tetrachloride, the rate of the dehydrobromination reaction gradually decreases, and the process has practically stopped after 10-12 hours, although at this time only about 69% of the theoretical amount of hydrogen bromide has been evolved. It is possible that the equilibrium (VI) ⇌(VII) is established during the process.

Since the hydrogen bromide evolved during the bromination leads to partial saponification of the ketal group (determined by spectroscopic analysis), which can cause side bromination reactions in the α-position to the 3-keto group, we carried out an experiment in which a small amount of pyridine was added to the reaction mixture. In this case also, after dehydrobromination in carbon tetrachloride, a substance containing 6.1% bromine was obtained. These results indicate that dehydrobromination in carbon tetrachloride at reflux temperature fails, by a considerable extent, to go to completion.

A change in the dehydrobromination conditions permitted us to accomplish readily the almost complete elimination of hydrogen bromide from (VI). Crude choladiene (VII), practically free from brominated impurities, was obtained when the reaction was carried out by heating in pyridine at 105-110° (two hours), by refluxing for two hours in a mixture of carbon tetrachloride and pyridine (4:1) after a preliminary refluxing in carbon tetrachloride (five hours), and by refluxing in glacial acetic acid (20 minutes). Interesting results were obtained during an attempt to carry out the dehydrobromination of (VI) in pyridine at room temperature. Under these conditions, along with choladiene, a substance which was readily soluble in alcohol was obtained. It contained nitrogen and bromine, and in aqueous-alcoholic solution it gave a precipitate with silver nitrate. On the basis of the analytical data and the ease of solution in alcohol and hot water, it may be assumed that this compound is the pyridine salt of the monobromide of 3-keto-24,24-diphenylcholene-3-ethylene ketal. Evolution of hydrogen bromide was not detected when this pyridine salt was heated (refluxed four hours) in carbon tetrachloride.

TABLE 1

Expt. No.	Amount of CCl_4 used	Excess of N-bromo-succinimide (%)	Bromination time (in min)	Yield of (VII) (in %)	Melting point of (VII)	Yield of pure (VII) with m.p. of 193.5-196.5° (in %)
1	20	6—7	5.5	51.2	189—193.5°	44.4
2	20	6—7	9—10	53.2	189—193.5	46.2
3*	20	6—7	9—10	49.7	188—192.5	—
4	20	6—7	20	53.2	189—193.5	46.2
5	20	15	9—10	58.2	189.5—193.5	50.5
6	45	15	9—10	65.3	190—193	56.7
7	45	20	9—10	63.25	191—193	55.2
8	80	15	9—10	72.3	191—192.5	65

*Experiment 3 was carried out without the addition of pyridine during bromination. The resulting reaction product was subjected, before purification, to the action of ethylene glycol in the presence of p-toluenesulfonic acid.

The investigation of the bromination of ketal (V) was carried out without isolating the bromide (V), which was subjected to dehydrobromination by refluxing in a mixture of carbon tetrachloride and pyridine (4 : 1), i.e., under conditions providing for complete elimination of the hydrogen bromide. A small amount of pyridine was added to the reaction mixture during bromination in order to prevent saponification of the ketal group. We determined the effect of the following variables on the yield of choladiene (VII): bromination time, excess of N-bromosuccinimide, and amount of carbon tetrachloride. The results of the experiments are presented in Table 1 (in all experiments, 1 g of ketal was used).

The data obtained show that a change in the bromination time from 5.5 to 20 minutes has almost no effect on the yield of (VII) (Experiments 1, 2 and 4); an increase in the excess amount of N-bromosuccinimide to 15% leads to an increase in the yield (Experiments 2 and 5). The yield of (VII) increased considerably with an increase in the amount of carbon tetrachloride present during bromination (Experiments 5 and 8).

The conversion of ketal (VII) to ketone (VIII) was carried out by refluxing (14 hours) an acetone solution of (VII) in the presence of p-toluenesulfonic acid. Oxidation of ketone (VIII) with chromium trioxide gave pregnane-3,20-dione.

EXPERIMENTAL

Investigation of the Dehydrobromination Reaction During the Preparation of $\Delta^{20,23}$-3-Keto-24,24-diphenylcholadiene-3-ethylene Ketal (VII)

a) Dehydrobromination in carbon tetrachloride and the kinetics of the reaction. 1 g of Δ^{23}-3-keto-24,24-diphenylcholene-3-ethylene ketal (V), m.p. 140.5-141.5°, was dissolved in 20 ml of dry carbon tetrachloride, 0.332 g of 99.5% N-bromosuccinimide was added, and the mixture was refluxed for twelve minutes in a stream of nitrogen and under illumination by a lamp (500 W) with a reflector. The evolution of hydrogen bromide began four minutes after the reaction was started; the hydrogen bromide was absorbed in an 0.1-N solution of sodium hydroxide. At the conclusion of the bromination, the excess alkali was back-titrated. 1.7 ml of the 0.1-N NaOH had been tied up. The reaction mixture was cooled with ice, the precipitated succinimide was filtered, and the filtrate was boiled for twelve hours in a flask fitted with a dropping funnel, a condenser arranged for distillation, and a receiver, which was connected to a scrubber containing an 0.1-N solution of sodium hydroxide. As the carbon tetrachloride distilled, a corresponding amount of fresh solvent was added. At specific time intervals, the distillate was collected and washed several times with water, and the solution of alkali was replaced. The aqueous extracts were combined with the alkaline solution, and the excess alkali was back-titrated. The results are presented in Table 2.

TABLE 2

Dehydrobromination time (in hrs)	Amount of 0.1-N NaOH reacted with HBr (in ml)	Amount of HBr evolved (in %)
1	3 } for each hour	16.2
2	2.72 } for each hour	30.8
3	2.4 } for each hour	43.7
6	2.25 } for each 3 hours	55.9
9	0.59 } for each 3 hours	59
12	0.23 } for each 3 hours	60.3

A total of 12.89 ml of the 0.1-N solution of sodium hydroxide was reacted during the bromination and hydrobromination; this corresponds to 69.4% of the theoretical amount of hydrogen bromide. At the conclusion of the reaction, the solvent was distilled under vacuum. The tarry residue was ground with alcohol, filtered, and washed with alcohol. 0.85 g of a substance with an m.p. of 157-171° was obtained. The substance contained 6% bromine. When the experiment was carried out without the nitrogen flow (dehydrobromination, 6.5 hours), the same results were obtained. A repetition of the experiment with the addition to the reaction mixture of 0.1 ml of dry pyridine resulted in 0.8 g of material with an m.p. of 167-179°. The bromine content was 6.1%. In

succeeding experiments, the bromination was carried out under the conditions described above (without the nitrogen flow). 1 g of Δ^{23}-3-keto-24,24-diphenylcholene-3-ethylene ketal (V), 20 ml of carbon tetrachloride, 0.35 g of 99.5% N-bromosuccinimide (5.4% excess), and 0.1 ml of pyridine were used. The dehydrobromination conditions were varied.

b) Dehydrobromination in a mixture of carbon tetrachloride and pyridine (4:1). At the end of the bromination and separation of the succinimide, the filtrate was refluxed for five hours, 5 ml of pyridine was then added, and the refluxing was continued for another two hours. The solvent was distilled under vacuum. The tarry precipitate, which still contained a certain amount of pyridine, was washed with alcohol. 0.76 g of a substance with an m.p. of 166-186° was obtained. It contained only traces of bromine. Recrystallization from a mixture of acetone and ethyl acetate (3:1) gave 0.456 g of a substance with an m.p. of 188-195°. A second recrystallization increased the m.p. to 193.5-196.5°. The substance was readily soluble in chloroform and difficultly soluble in alcohol, ether, and acetone.

Found %: C 84.92; H 8.82. $C_{39}H_{48}O_2$. Calculated %: C 85.02; H 9.01.

c) Dehydrobromination in glacial acetic acid. After separation of the succinimide and distillation of the carbon tetrachloride under vacuum, 25 ml of glacial acetic acid was added to the residue, and the mixture was refluxed for 20 minutes. The acetic acid was distilled under vacuum, and the tarry residue was dissolved in benzene. The benzene solution was washed with sodium bicarbonate solution and then with water, and the benzene was distilled under vacuum. The remaining material was washed with alcohol. 0.7 g of a substance with an m.p. of 154-179° was obtained. It contained only a trace of bromine.

d) Dehydrobromination by heating in pyridine. The experiment was carried out in 10 ml of pyridine for two hours at 105-110°. The pyridine was distilled under vacuum (30-35°). The remaining tarry material was dissolved in benzene. The benzene solution was washed with dilute hydrochloric acid and water. The residue remaining after distillation of the benzene under vacuum was washed with alcohol. 0.83 g of a substance with an m.p. of 160-180° was obtained. It contained only traces of bromine. Recrystallization from a mixture of acetone and ethyl acetate (3:1) increased the m.p. to 190-192°. The weight was 0.39 g.

e) Dehydrobromination in pyridine at room temperature. The experiment was carried out in 15 ml of pyridine for 20 hours at room temperature. Separation of the substance was carried out as described above (d). 0.36 g of a substance with an m.p. of 150-175° was obtained. It contained only a trace of bromine. Recrystallization increased the m.p. to 193.5-196°. The alcohol filtrate was concentrated under vacuum. A dark, tarry substance (0.54 g) remained; it did not evolve hydrogen bromide when heated (refluxed four hours) in carbon tetrachloride. The carbon tetrachloride was distilled under vacuum. The tarry residue solidified when ground with ether. The material was filtered, washed with ether, and dried at 60°. 0.4 g of a substance with an m.p. of 128-132° was obtained. Additional drying at 100° for eight hours did not change the melting point.

Found %: N 1.92; Br 11.5. $C_{43}H_{54}O_2NBr$. Calculated %: N 2.01; Br 11.47.

The substance was readily soluble in alcohol and hot water, and was insoluble in ether. The addition of ether to an alcoholic solution of the material and the cooling of an aqueous solution caused separation of the substance in the form of an oil. The action of silver nitrate on a solution of the substance in aqueous alcohol precipitated silver bromide.

Investigation of the Bromination of Δ^{23}-3-Keto-24,24-diphenylcholene-3-ethylene Ketal (V)

The bromination method was analogous to that described above. 1 g of ketal (V), m.p. 140.5-141.5°, was dissolved in carbon tetrachloride, and the N-bromosuccinimide (99.5%) and 0.1 ml of pyridine were added. The reaction mixture was refluxed under illumination from two lamps (500 W). The reaction conditions were varied.

In all experiments (except experiment 8) the dehydrobromination was carried out under uniform conditions, as described in (b) above. Experiment 8 was carried out by the same method in a mixture of carbon tetrachloride and pyridine (6:1). In contrast to the method described previously under (b), separation of the material was carried out after removal of the pyridine by washing with water and a dilute solution of hydrochloric acid. The results of these experiments are presented in Table 1.

Preparation of $\Delta^{20,22}$-3-Keto-24,24-Diphenylcholadiene (VIII)

2 g of $\Delta^{20,22}$-3-keto-24,24-diphenylcholadiene-3-ethylene ketal (VII) was dissolved in 100 ml of dry acetone, 0.1 g of p-toluenesulfonic acid was added, and the mixture was refluxed for 14 hours. Part of the acetone was distilled (about 50 ml), the mixture was diluted with water, and the resulting precipitate was filtered, washed with water to a neutral reaction, and dried at 60°. The substance was recrystallized from acetone. 1.02 g of a substance with an m.p. of 187-190° was obtained. A second recrystallization from acetone and drying under vacuum at 100° increased the melting point to 191-193° (0.83 g). An additional 0.31 g of the substance, m.p. 190-192°, was separated from the filtrate. The substance was readily soluble in chloroform, soluble in ether, and sparingly soluble in alcohol and acetone.

Found %: C 87.95; H 8.83. $C_{36}H_{44}O$. Calculated %: C 87.75; H 9.00.

Preparation of Pregnane-3,20-dione

0.9 g of $\Delta^{20,22}$-3-keto-24,24-diphenylcholadiene (VIII) was oxidized with 0.74 g of chromium trioxide in a mixture of chloroform and 80% acetic acid at 2° and with stirring, which was continued for two hours at 5-10°, and the reaction mixture was then allowed to stand at 10-14° for 15 hours. After the usual treatment, 0.6 g of a tarry substance was separated, washed with hexane and with ether, and recrystallized from aqueous alcohol. The m.p. was 119-121°. A mixture with known pregnane-3,20-dione showed no depression of the melting point.

SUMMARY

The bromination with N-bromosuccinimide of Δ^{22}-3-keto-24,24-diphenylcholene-3-ethylene ketal and the dehydrobromination of the corresponding 22 bromide were investigated.

$\Delta^{20,22}$-3-Keto-24,24-diphenylcholadiene-3-ethylene ketal and $\Delta^{20,22}$-3-keto-24,24-diphenylcholadiene were prepared. The latter was converted to pregnane-3,20-dione.

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A NEW ALKALOID FROM THE CENTRAL ASIATIC LARKSPUR

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The material for our work comprised the underground parts of a larkspur closely related to a known species of mountain larkspur (Delphinium Oreophilum Huth), but differing from it in morphological characteristics. The plant was collected on the VNIKhFI [All-Union Chemical-Pharmaceutical Scientific Research Institute] expedition, under the direction of P.S. Massagetov, in the Aksu-Dzhebogla National Forest in the Southern Kazakhstan District. The original material was collected on August 3, 1954 at an altitude of 1600 meters; the plants were in the flowering phase.

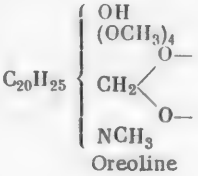
The total bases (0.69% of the weight of dry plant) were extracted with dichloroethane. Paper chromatography established the presence of five alkaloids with R_f 0.35, 0.47, 0.55, 0.68, 0.81.

The present paper describes the separation and investigation of the two alkaloids present in the plants in the greatest amounts, those with R_f 0.47 and 0.55. These alkaloids, which are designated, respectively, (I) and (II), could be separated by virtue of the differing solubilities of the bases and their salts.

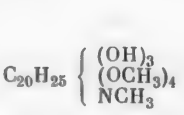
Alkaloid (I) had a composition corresponding to the formula $C_{26}H_{43}O_7N$; it contained one OH group, four OCH_3 groups, a methylenedioxy group, and an N-alkyl group, and it did not contain an ester group. The infrared absorption spectrum of base (I) was closely similar to that of lycoctonine; it contained a band characteristic of the OH group in the 3500 cm^{-1} region, and did not contain the carbonyl band.

This is a new alkaloid. We propose for it the name oreoline.

After saponification of the methylenedioxy group in oreoline, a substance was obtained with the composition $C_{25}H_{43}O_7N$, which contained three OH groups, four OCH_3 groups, and an N-alkyl group. Bands characteristic of hydroxyl groups were present in the infrared spectrum, while carbonyl bands were absent.



Oreoline



Product from saponification of methylenedioxy group in oreoline

Alkaloid (II) was obtained, in the form of the perchlorate, from the mother liquor remaining from the isolation of the oreoline. This alkaloid was identical with methyllycaconitine.

Work continues on the further investigation of the total alkaloids.

EXPERIMENTAL

Extraction of the alkaloids from the plants. 14 kg of the ground plants was wetted with a 5% solution of sodium carbonate, and was extracted with dichloroethane in a percolation apparatus. The extract was treated with sulfuric acid, and the aqueous layer was agitated twice with ether. The aqueous layer was made alkaline with a 5% solution of sodium carbonate, and was exhaustively extracted with ether and then with chloroform. 77 g of material (Fraction a) was obtained from the ether extract, and 19.5 g of material (Fraction b) was obtained

from the chloroform extract. By means of paper chromatography on No. 4 paper (solvent – the upper phase of a mixture of butanol, water and acetic acid taken in the ratio 50 : 50 : 1; time – about 15 hours; temperature – 18-19°; developer – Dragendorff's solution), it was established that Fraction a contained five alkaloids with R_f 0.35, 0.47, 0.55, 0.68, 0.81, and Fraction b contained four alkaloids with R_f 0.36, 0.56, 0.69, 0.82. As may be seen from the R_f values, both the ether and chloroform fractions consisted of the total alkaloids, except for the absence from the chloroform fraction of the substance with an R_f of 0.47, which was completely extracted by ether and which, from the size and intensity of the spot, was the major substance in the total alkaloids.

Isolation of oreoline. 77 g of Fraction a was crystallized from acetone and then twice from alcohol; 6.7 g of oreoline was obtained, m.p. 211-213° (under vacuum), $[\alpha]_D$ −28° (conc. 1.0, chloroform) and $[\alpha]_D$ +55.1° (conc. 1.0, alcohol). The substance was insoluble in water, difficultly soluble in alcohol and acetone, and soluble in ether and chloroform.

Found %: C 64.58; H 8.58; N 3.0; OH 3.45; OCH_3 24.52. $C_{21}H_{26}(OH)(OCH_3)_4(CH_2O_2)N$. Calculated %: C 64.8; H 8.9; N 2.9; OCH_3 25.77; OH 3.53.

An additional 4 g of impure oreoline was obtained by evaporation of the mother liquors.

The hydrochloride of oreoline was prepared by acidification of a solution of the base in anhydrous alcohol with an alcoholic solution of HCl followed by the addition of absolute ether until the solution became turbid; after two crystallizations from alcohol-ether mixture, the m.p. was 186-188°. The substance was readily soluble in water, alcohol, and acetone.

Found %: C 60.68; H 8.4; Cl 6.82. $C_{26}H_{43}O_7N \cdot HCl$. Calculated %: C 60.3; H 8.31; Cl 6.86.

Oreoline perchlorate was prepared by the addition of an aqueous solution of magnesium perchlorate to a solution of the base in 10% HCl. After two recrystallizations of the perchlorate from a mixture of alcohol and ether, the m.p. was 139-142°.

Found %: N 2.33; Cl 6.24. $C_{26}H_{43}O_7N \cdot HClO_4$. Calculated %: N 2.40; Cl 6.02.

Isolation of methyllycaconitine. The mother liquors remaining after the separation of the oreoline were evaporated under vacuum; the residue was dissolved in sulfuric acid; the solution was washed with ether, made alkaline with sodium carbonate, and extracted with ether; 26 g of the amorphous base was obtained. This was dissolved in 10% HCl, and an excess of magnesium perchlorate was added. 7.5 g of the perchlorate was obtained, m.p. 190-194° (from 50% alcohol), $[\alpha]_D$ +27° (conc. 0.4, alcohol). A mixture with a known sample of methyllycaconitine [1] showed no depression of the melting point. From the filtrate remaining after the separation of the methyllycaconitine was obtained 12 g of a mixture of amorphous bases, the separation of which by chromatographing over Al_2O_3 gave a small amount of oreoline and methyllycaconitine.

Saponification of the methylenedioxy group. 5.25 g of oreoline and 3.53 g of phloroglucinol were dissolved in 330 ml of hydrochloric acid (1:1) and heated for two hours at 70-80°. Further treatment was by the method described previously [2]. 2.65 g of the phloroglucide was obtained; this corresponds to a single methylenedioxy group.

From the aqueous solution was isolated 1.7 g of a base with an m.p. of 73-75° (from ether), $[\alpha]_D$ +64.2° (conc. 1.0, alcohol), R_f 0.45 (when chromatographed under the previously described conditions). The substance was insoluble in water, difficultly soluble in ether, and readily soluble in alcohol, acetone, methanol, and chloroform.

Found %: C 64.0; H 8.8; N 3.21; OH 11.75; OCH_3 27.67; NCH_3 5.38. $C_{20}H_{25}(OH)_3(OCH_3)_4NCH_3$. Calculated %: C 63.9; H 9.0; N 2.98; OH 10.87; OCH_3 26.43; NCH_3 6.10.

In view of the close agreement in the analyses, it can be assumed that the nitrogen is bound to a CH_3 group.

A crystalline perchlorate, hydrochloride, oxalate, or picrate could not be prepared. An additional 1 g of the substance was separated from the mother liquor.

SUMMARY

From the mountain larkspur (Delphinium Oreophilum Huth.) was separated 0.69% total bases, the separation of which gave a new alkaloid and also methyllycaconitine.

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PREPARATION OF HYDRATROPIC ALCOHOL

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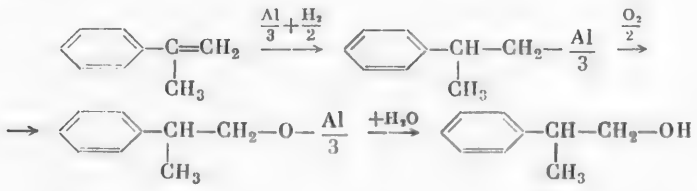
2-Phenyl-1-propanol, or hydratropic alcohol, is of considerable interest as an aromatic principle. This product presently finds application as a "lilac" base in modern perfume compositions [1]. The method used in producing hydratropic alcohol has not been published; however, there is basis for the assumption that its synthesis is accomplished by the reduction of hydratropic aldehyde, which has previously been described in the literature.

Thus, [2] described a process for the reduction of hydratropic aldehyde with activated powdered magnesium in an alcoholic medium; Cohen and co-workers [3], who prepared a series of derivatives of hydratropic alcohol, started with the synthesis of the alcohol from hydratropic aldehyde. Finally, Ramart and Amagat [4] prepared hydratropic alcohol by a multistage synthesis, starting with the nitrile of hydratropic acid and proceeding through the amide, which was reduced with metallic sodium in anhydrous alcohol; along with the hydratropic alcohol, this synthesis also formed the corresponding amine as a by-product. This last method is hardly satisfactory for use in industry. Hydratropic aldehyde, which is a starting material for the preparation of hydratropic alcohol, is, in turn, produced on an industrial scale from acetophenone and esters of monochloroacetic acid through phenylglycidic acid [5]. The multistage nature and the complexity of the methods described above for the synthesis of hydratropic alcohol limit the possibility of using this valuable aromatic principle.

In recent years, Ziegler and co-workers [6] have described in general terms a scheme for the preparation of primary alcohols by oxidation of trialkylaluminums and subsequent hydrolysis of the aluminum alcoholates. For the preparation of the trialkylaluminums, Ziegler used a reaction, discovered by him, between olefins, aluminum, and hydrogen; he has published general information on this reaction in a series of articles [7].

It was very tempting to use the Ziegler reaction for the preparation of hydratropic alcohol (I) according to the scheme presented below.

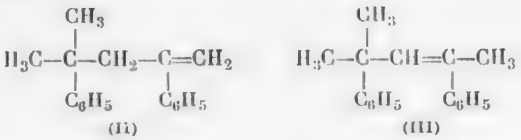


(I)

With synthesis conditions giving good yields, this would be the simplest method and a technically practicable one, since the initial organic component is α-methylstyrene, which is a product of basic organic synthesis.

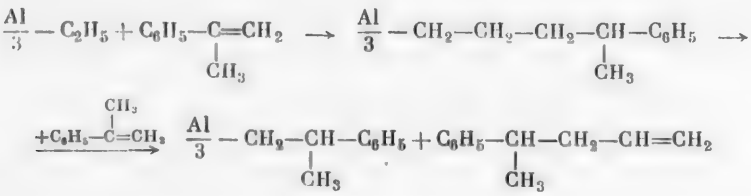
In Ziegler's work [8] on the interaction of olefins, aluminum, and hydrogen, there were indications of the possibility of carrying out the reaction in one stage or in two with the preliminary formation of a dialkylaluminum hydride and subsequent interaction of the latter with the olefin. We confirmed both of these possible variants. Moreover, it was found that the yield of hydratropic alcohol is lower when the reaction is carried out in a single stage owing to the formation of a dimer of α-methylstyrene. In any case, apart from the formation of the dimer of α-methylstyrene, isopropylbenzene is formed, apparently as a result of hydrogenation of the α-methylstyrene in the presence of the heavy metals contained in the aluminum, these metals acting as hydrogenation catalysts.

The fact of the formation of the α-methylstyrene dimer is interesting in connection with the statement by Ziegler [8] that olefins having the isobutylene structure are incapable of polymerizing in the presence of trialkylaluminums. It can be assumed that the structure of the α-methylstyrene dimer obtained in this reaction corresponds to formula (II) and is different from the dimer obtained by Staudinger [9] (III) in the presence of stannic chloride, since in the polymerization of olefins by the Ziegler method, higher olefins with the double bond in the α-position are always formed.



(II) (III)

Apart from the compounds indicated, a small amount of 2-phenyl-1-pentene was formed during the synthesis of hydratropic alcohol; we explain the formation of this compound by the interaction of triethylaluminum (used as an activator for the aluminum) and α-methylstyrene with subsequent displacement of the olefin by α-methylstyrene.



When the interaction of α-methylstyrene, aluminum, and hydrogen is carried out in two stages, practically no α-methylstyrene dimer is formed; the yield of hydratropic alcohol in this case amounts to 55% calculated on the α-methylstyrene.

EXPERIMENTAL

The α-methylstyrene was prepared by dehydration of dimethylphenylcarbinol at atmospheric pressure over anhydrous aluminum oxide in the presence of iodine. The crude product was washed with an aqueous solution of sodium hydroxide, dried with potassium carbonate, and distilled in a column over metallic sodium. A product was obtained with a b.p. of 161°, n_D^{25} 1.5325; the literature values are 161-162°, n_D^{17} 1.5330 [10]. The finely divided aluminum (1-5μ particle size) was used as a suspension in gasoline range hydrocarbons (b.p. 95-105°). Triethylaluminum (2-5% by weight of the total charge) was used to activate the aluminum. The hydrogen used in the synthesis was preliminarily freed from traces of oxygen and moisture.

The experiments were carried out in a 1-liter, stainless steel autoclave fitted with a stirrer, a manometer, and an electric heater. When the synthesis was carried out in two stages, the suspension of aluminum and triethylaluminum (74% solution in gasoline-range hydrocarbons) was charged to the autoclave under a stream of oxygen-free nitrogen. Hydrogen was then fed to the autoclave. The contents of the autoclave were heated to 80° with the stirrer in operation. The heating was continued for an hour, after which the temperature was lowered to 50°, and the α-methylstyrene was charged. The reaction mixture was heated to 140°. When this temperature was reached, the pressure dropped sharply (from 80 to 35 atm) over a period of several minutes, after which it was restored to the original value with hydrogen. The process was stopped when no further pressure drop was observed. The entire synthesis required about two hours counting the time from after the charging of the α-methylstyrene.

When the reaction was carried out in a single stage, all components were charged simultaneously, after which hydrogen was charged to the reactor and the stirrer and heater were switched on. In this case, the pressure began to drop when the temperature reached 95°; the absorption of hydrogen ceased at 120-130°.

The oxidation was carried out in a conical flask fitted with a stirrer, a thermometer (submerged in the liquid), a reflux condenser, and a tube extending almost to the bottom of the flask for the introduction of dry air (or oxygen). The process proceeded with the evolution of heat; the temperature was maintained at not above 70° by controlling the air feed rate and the rate of stirring. After the temperature decrease occurring during the

feeding of air, the oxidation was completed with oxygen; with the introduction of the oxygen, there was first observed a rise in temperature followed by a rapid decrease to room temperature, after which the feeding of oxygen was continued for another hour. Since excess aluminum was introduced into the reaction, aluminum was always present in the reaction mixture removed from the autoclave; experiments showed that the presence of aluminum had no effect on the oxidation process.*

The hydrolysis was carried out with 10-15% hydrochloric acid while stirring. The order of addition of the reagents had no effect. If the reaction mixture contained aluminum after the oxidation, a larger amount of hydrochloric acid was required for complete solution. After hydrolysis of the reaction mixture, the oil layer was separated from the lower, aqueous layer. The latter was extracted with ether (2-3 times with 50-ml portions). The ether extracts were combined with the oil layer, and the solution was washed with a solution of sodium carbonate or potassium carbonate, dried with potassium carbonate, and distilled in a column. The results of the experiments on the preparation of hydratropic alcohol are presented below.

1. The single-stage reaction of α-methylstyrene, aluminum, and hydrogen. 300 g of α-methylstyrene, 50 g of aluminum, 250 g of gasoline-range hydrocarbons, and 25 g of 74% triethylaluminum were charged to the autoclave. The initial hydrogen pressure was 50 atm. The pressure began to drop when a temperature of 95° (85 atm) was reached, and it continued to drop over a period of three hours (highest temperature was 130°). 515 g of reaction mixture was used in the oxidation. After hydrolysis of the oxidation product and distillation of the solvents (ether and gasoline hydrocarbons), the mixture was vacuum distilled. Four fractions were obtained.

The first fraction (88 g) was isopropylbenzene.

B.p. 29-30° at 8 mm, n_D^{20} 1.4928. Literature data: b.p. 26.8° at 5 mm [11], n_D^{20} 1.4930 [12].

The second fraction was 2-phenyl-1-pentene (12 g).

B.p. 40-50° at 5 mm, n_D^{25} 1.5054, d_4^{25} 0.8684, MR_D 49.96; calc. 48.92; bromine number 106.2; calc. 109.3.

The third fraction was hydratropic alcohol (93 g; 33% yield calculated on the α-methylstyrene).

B.p. 85° at 3 mm, n_D^{26} 1.5225, d_4^{26} 1.00, MR_D 41.60; calc. 41.68. According to literature [1]: b.p. 114° at 14 mm, n_D 1.5262, d 1.01.

Found %: C 79.17; H 9.40. $C_9H_{12}O$. Calculated %: C 79.36; H 8.88.

The phenylurethan of the hydratropic alcohol had an m.p. of 54-56°.

Found %: C 75.01; H 6.69; N 5.75. $C_{16}H_{17}O_2N$. Calculated %: C 75.28; H 6.69; N 5.48.

The fourth fraction was a dimer of α-methylstyrene (47 g).

B.p. 170-175° at 8 mm, n_D^{25} 1.5636, d_4^{25} 0.9850, MR_D 77.96; calc. 77.65 (for 4-methyl-2,4-diphenyl-1-pentene, II).** Bromine number 65.1; calc. 67.6.

According to [13]: for the dimer of α-methylstyrene, b.p. 166-167° at 10 mm, d_4^{25} 0.9850, n_D^{25} 1.5636.

Found %: C 89.67; H 8.52. $C_{18}H_{20}$. Calculated %: C 91.50; H 8.55.

2. The two-stage reaction of α-methylstyrene, aluminum, and hydrogen was carried out as indicated above. 50 g of aluminum in 250 g of gasoline-range hydrocarbons and 5 ml of 74% triethylaluminum were used in the reaction. 154 g of α-methylstyrene was added at the end of the first stage of the reaction. When a temperature of 140° was reached, the pressure dropped to 35 atm over a period of one hour and fifteen minutes. 400 g of reaction mixture was discharged from the autoclave. After the oxidation and hydrolysis, the reaction products were distilled. Fractions identified as in the preceding case were obtained. The yield of hydratropic alcohol by this method was 55% calculated on α-methylstyrene.

*When required, the aluminum could be filtered in a stream of dry, oxygen-free nitrogen. The unreacted aluminum could be used in a subsequent synthesis.

**For the α-methylstyrene dimer prepared by Staudinger [9], namely, 2-methyl-2,4-diphenyl-3-pentene (III): b.p. 118-120° at 0.1 mm, d_4^{20} 1.0038, n_D^{20} 1.5633, MR_D 76.29; calc. 77.65.

SUMMARY

1. The synthesis of hydratropic alcohol from α-methylstyrene through organoaluminum compounds was carried out with a yield of 55%. The simplicity of the preparation of the alcohol from available starting materials makes this method the simplest for industrial use.

2. The composition of the by-products formed during the synthesis of hydratropic alcohol was investigated; an explanation of the mechanism of their formation was given.

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ELECTROSYNTHESIS OF NICOTINIC ACID

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There has appeared in the literature only a very small amount of work devoted to the electrolytic oxidation of β-picoline to nicotinic acid and of quinoline to quinolinic acid (the latter is readily decarboxylated to nicotinic acid). Thus, an attempt to oxidize electrolytically α-, β-, and γ-picolines to the corresponding aldehydes resulted in low yields [1]. The electrolytic oxidation of β-picoline in 30% sulfuric acid to nicotinic acid and of quinoline in 75-80% sulfuric acid to quinolinic acid has been accomplished [2]. According to other data [3], the oxidation of quinoline should be carried out in 40% sulfuric acid. Attempts at the electrosynthesis of nicotinic acid from nicotine [4], anabasine [5, 6], and N-methylanabasine [5] have been described.

An electrochemical method for the preparation of nicotinic and quinolinic acids is of great interest, since it does not involve the use of oxidizing agents and catalysts. However, the data available in the literature are insufficient for practical use of this method.

In the present work on the electrolytic oxidation of β-picoline, we studied the effect of the quantity of electricity passed through the electrolyte, the current density, the temperature, the addition of Mn^{++} and Cr^{+++}, and the concentration of β-picoline and of sulfuric acid on the yield (B) of nicotinic acid and on the current efficiency (A). The effect of the electrolysis conditions on the rate of oxidation of β-picoline and nicotinic acid was also studied.

In addition, the effect of the concentration of sulfuric acid and of quinoline on the yield of nicotinic acid in the electrolytic oxidation of quinoline was studied.

EXPERIMENTAL

Method. The following method was used for the preparation of pure β-picoline. The nonbasic impurities were steam-distilled from a picoline fraction (b.p. 138-144°) acidified with sulfuric acid. The free bases were made alkaline, and the β-picoline was then separated in the form of the difficultly soluble salt $CuSO_4 \cdot 5H_2O \cdot 2C_6H_7N$ [7]. β-Picoline of 98-99.5% purity was obtained by threefold recrystallization by cooling; the purity was determined by the freezing point method [8].

The experiments on the electrosynthesis of nicotinic acid were mainly carried out using a lead anode in sulfuric acid solution. It was also possible to use a platinum anode with the same solution, but the yield of nicotinic acid was somewhat less. Magnetite and graphite anodes in acid medium and also platinum, iron, and nickel anodes in alkaline medium were inactive.

The electrolytic cell was an 0.5-liter beaker 130 mm in diameter and 75 mm high, inside of which was placed a ceramic diaphragm 58 mm in diameter and 145 mm high and impregnated with water glass to decrease the permeability [9]. A cylindrical anode (2 sq. dm. surface area), prepared from sheet lead, surrounded the diaphragm. The volume of anolyte was ~50 ml. The volumetric current density in the anolyte varied up to 1000 amp/liter. The lead cathode (1 sq. dm. surface area) was inside the diaphragm in the beaker. The catholyte was 10-20% sulfuric acid. The cell was placed in a thermostatted bath. At the conclusion of an experiment, the anolyte was filtered free from slime, neutralized with sodium carbonate, then acidified with acetic acid to a pH of 4-4.5, and heated on a boiling-water bath. Copper sulfate or acetate was added to the hot solution, and the heating was continued for an additional several hours. The resulting precipitate of copper nicotinate was determined gravimetrically. The yield of nicotinic acid was calculated from the amount of copper nicotinate and was

based on the weight of the original β-picoline. In order to isolate the nicotinic acid, the copper salt was treated with a solution of sodium sulfide, the copper sulfide was filtered, and the free nicotinic acid was precipitated (pH 3.3) by acidification of the filtrate with hydrochloric acid. Loss during the separation was ~10%.

Oxidation of quinoline and separation of the quinolinic acid as the copper salt were carried out similarly. In the experiments on the oxidation of quinoline, the amount of electricity passed was 28 F/mole of the initial material, i.e., 155% of that calculated from the reaction

$$C_9H_7N + 9[O] \rightarrow C_5H_3N(COOH)_2 + 2CO_2 + H_2O$$

Electrolytic oxidation of β-picoline. The effect of the quantity of electricity passed through the electrolyte (Q*) on the current efficiency (Curve 1) and on the yield (Curve 2) is shown in Fig. 1. The experiments were carried out under the following conditions: temperature, 40°; anode current density, 10 amp/dm²; anolyte, 1 M solution of β-picoline in 7 N sulfuric acid.

The low current efficiency observed at the beginning of the electrolysis (Fig. 1) indicates the formation of intermediate products of the oxidation of β-picoline, apparently pyridine-3-carboxaldehyde, which is in agreement with the literature [1]. The maximum yield of nicotinic acid (52-54%) was obtained when 150-200% of the theoretical amount of electricity had been charged. When Q exceeded 200%, practically no β-picoline remained in the anolyte.

As follows from the graphs of the data, the nicotinic acid formed as a result of oxidation of β-picoline is rather easily oxidized further. However, the oxidation of β-picoline proceeds at a considerably greater rate, owing to which it is possible to obtain nicotinic acid in rather high yield. Specially conducted experiments on the electrolytic oxidation of nicotinic acid (Table 1) permit a comparison of the over-all current efficiencies during the electrolytic oxidation of β-picoline and nicotinic acid.

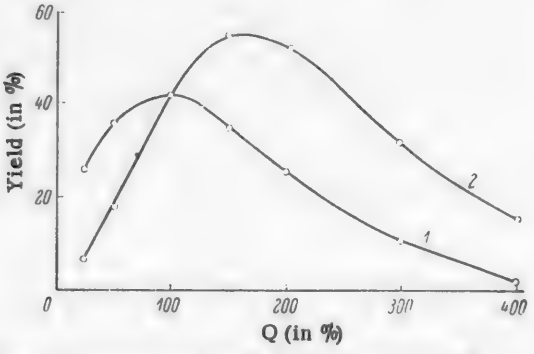

Fig. 1. Variation in yield of nicotinic acid with quantity of electricity passed: 1) current efficiency; 2) yield.

The over-all current efficiency for all oxidation products was determined from the volume of oxygen evolved during electrolysis of a sulfuric acid solution of β-picoline or nicotinic acid (v_1) as compared to the volume of oxygen evolved in the same time from a solution of pure sulfuric acid of the same concentration (v_2). The fraction of the current consumed in the oxidation of the organic substances is:

$$A_1 = \frac{v_2 - v_1}{v_2}.$$

*A Q of 100% corresponds to the theoretical amount (6 F/mole).

TABLE 1

Concentration of β-picoline or nicotinic acid (M)	Over-all current efficiency for all oxidation products (in %) during oxidation of	
	β-picoline	nicotinic acid
0.01	15	0
0.1	62	11
1.0	94	43

Note: Experimental conditions: temperature, 40°; current density, 5 amp/dm^2; sulfuric acid concentration, 7.5 N.

In a study of the effect of anolyte temperature, it was found that the maximum yield is obtained at 30-40° (Table 2). The decrease in the yield of nicotinic acid with an increase in temperature above 40° is apparently due to acceleration of the side reactions, since the over-all rate of all oxidation processes was almost unchanged with the increase in temperature.

TABLE 2

Q (in %)	Yield (in %) at an anolyte temperature of				
	20°	30°	40°	60°	80°
50	15	–	21.5	–	–
100	39	–	41	38	36
150	45	53	54	42	37
200	48	54	54	47	35
250	44	48	46	–	–

Note: Experimental conditions: current density, 5 amp per dm^2; sulfuric acid concentration, 3.5 N; β-picoline concentration, 1 M.

A change in the anode current density within the limits of 1-10 amp/dm^2 had little effect on the yield of nicotinic acid (Table 3). Nor did the introduction of small amounts of Mn^{++} and Cr^{+++} have an appreciable effect (under the experimental conditions of Table 3 at a current density of 5 amp/dm^2).

TABLE 3

Q (in %)	Yield (in %) at an anode current density of (in amp/dm^2)			
	1	3	5	10
50	25	23	21.5	18
100	47	43	41	42
150	56	56	54	55
200	51	50	54	53
250	45	48	46	48

Note: Experimental conditions: temperature, 40°; β-picoline concentration, 1 M; sulfuric acid concentration, 7 N.

A change in the acidity of the anolyte within the limits of 11 to 17 N had almost no effect on the yield (Fig. 2). An increase in the initial concentration of sulfuric acid to 25 N led to a decrease in the yield to 32-34%

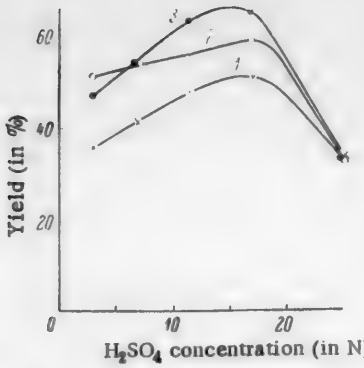

Fig. 2. Variation in the yield of nicotinic acid with concentration of sulfuric acid in the anolyte. (Concentration of β-picoline, 1 M; temperature, 40°; current density, 5 amp/dm².) Values of Q (in %): 1) 100; 2) 200; 3) 150.

as a result of considerable corrosion of the anode during the electrolysis.

An increase in the acidity of the anolyte during electrolysis owing to the passage of electricity was proportional to the quantity of electricity passed; therefore, during the study of the effect of the concentration of β-picoline, the initial concentration of sulfuric acid was chosen so that the average acidity during the electrolysis was approximately the same in all experiments and remained within the limits corresponding to maximum yield of nicotinic acid (Table 4).

From the data presented, it follows that the electrolytic oxidation of β-picoline to nicotinic acid can be successfully carried out under a wide range of electrolysis conditions, the yield of nicotinic acid reaching 65% at a current efficiency of 43% under the same conditions. When the process is carried out on a larger scale, it is possible that it will be more expedient to produce nicotinic acid at maximum current efficiency (55%), passing 100% of the theoretical amount of electricity rather than 150-200%, and to extract the unoxidized β-picoline from the solution after electrolysis.

TABLE 4

Q (in %)	Yield of nicotinic acid (in %) at concentrations of					
	β-picoline, 1 M	sulfuric acid, 17 N	β-picoline, 1.7 M	sulfuric acid, 15.5 N	β-picoline, 3.5 M	sulfuric acid, 13 N
100	51		55		49	
150	65		65		57	
200	59		59		44	

Note: Experimental conditions: temperature, 40°; current density, 5 amp/dm².

TABLE 5

Sulfuric acid concentration (in %)	25	38	52	65	75
Yield of quinolinic acid (%)	Trace	40	50	54	59

Note: Experimental conditions: temperature, 70-75°; current density, 2 amp/dm²; quinoline concentration, 100 g/liter.

TABLE 6

Quinoline concentration (in g/liter)	7	35	70	100	140
Yield of quinolinic acid (in %)	32	47	52	59	58

Note: Experimental conditions: temperature, 70-75°; current density, 2 amp/dm²; sulfuric acid concentration, 75%.

Electrolytic oxidation of quinoline. During the oxidation of quinoline, a change in the anode current density from 1 to 4 amp/dm^2 had no substantial effect on the yield of quinolinic acid. Electrolysis at higher current densities led to a significant increase in the volume of the anolyte owing to considerable gas formation. In experiments carried out at room temperature, the solution contained a considerable amount of tar after the electrolysis; it was not possible to separate the quinolinic acid. Better results (yields up to 60%) were obtained at an anolyte temperature of 78-80°. A further increase in the temperature led to a decrease in the yield. The electrolytic oxidation of quinoline to quinolinic acid proceeds not only in 65-75% but also in 40-50% sulfuric acid (Table 5), although, according to the data of M. Kulka [2], quinolinic acid is not formed in solutions with a sulfuric acid concentration of 50% or less.

During the study of the effect of quinoline concentration on the yield of quinolinic acid, it was found that the optimum concentration is 100-140 g/liter (Table 6); this is approximately one-third the concentration recommended in [2].

An advantage of the oxidation of quinoline in 40-50% sulfuric acid, with a quinolinic acid yield of 40-50% and a current efficiency of 20-25%, is the considerably less anode corrosion under these conditions. Concentrated solutions of quinoline foam strongly during electrolysis.

SUMMARY

1. The electrolytic oxidation of β-picoline to picolinic acid was investigated with respect to the effect of solution composition and electrolysis conditions.

2. It was established that nicotinic acid can be obtained at a maximum current efficiency of 55%; the maximum yield was 65%.

3. It was found that nicotinic acid is oxidized electrolytically, but with greater difficulty than β-picoline.

4. It was shown that it is possible to oxidize quinoline electrolytically to quinolinic acid at a lead anode with a yield of up to 60%.

5. The electrochemical method for the preparation of nicotinic and quinolinic acids can be recommended for practical use.

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DISCUSSION SERIES

CONJUGATION IN, AND THE DUAL REACTIVITY OF, BUTADIENE

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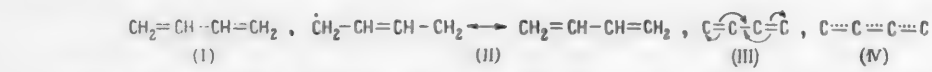
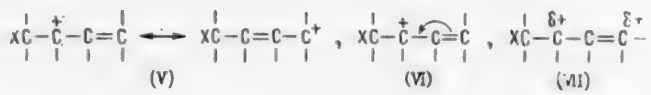
1. In one widely accepted chemical theory, the dual reactivity of π-conjugated systems is explained by a mesomeric structure of these molecules both in their natural state and in the form of carbonium ions formed during the course of the reaction. According to this theory, the 1,3-butadiene molecule, owing to the mesomeric effect (in other terms – the effect of static conjugation), cannot be represented by the usual classical structural formula with alternating double and single bonds (I), but only by formulas of the type of (II), (III), and (IV).



(I) (II) (III) (IV)

Formulas (II-IV) express the assumption of the equalization of the bonds in 1,3-butadiene, both with respect to the distribution of π-electron density [1] and with respect to the ratios of bond lengths [2]. According to this theory, it is precisely this mesomeric structure of 1,3-butadiene which leads to a concentration of the electron density at the 1 and 4 atoms, and thereby creates conditions favorable for the approach of an electrophilic reagent to these atoms; the resulting mesomeric carbonium ion also has a mesomeric structure (V-VII) – its positive charge "is not localized at the second carbon atom" [3], but is distributed along the bonds



(V) (VI) (VII)

Owing to this, in the second stage of the reaction, the anion of the reagent "can attack both the second and the fourth carbon atoms" [3], thereby exhibiting the dual reactivity of such compounds [4-6].

2. As confirmation by direct physical experiment, the authors of this theory attempted to assemble the experimental data on interatomic distances through a comparison of the lengths of double and single bonds in π-conjugated systems, on the one hand, and in ethylene and ethane as standards, on the other*; they attempted to establish an equality of the lengths of the bonds in π-conjugated systems and to establish thereby their mesomeric structure [7]. However, a more detailed consideration of the experimental material shows the complete incompetence of such an illustration. Actually, it is an undoubted experimental fact that the interatomic distance of the single C–C bond in 1,3-butadiene (1.46±0.03 A [8]) is shortened in comparison with the C–C bond in ethane (1.55±0.03 A [9]). The difference in the available results of experimental measurements of the interatomic distance in the C=C bonds in 1,3-butadiene (1.35±0.02 A [3]) and ethylene (1.353±0.001 A [10], 1.34±0.02 A [9], 1.33 A [10]) lies within the limits of experimental error, and, in any case, does not permit the conclusion as to the lengthening of the double bonds in 1,3-butadiene.** Electron diffraction measurements of the lengths of the

*See [1], p. 38.

**We note that in another paper [11], the author of [2], cited above, was himself forced to state that, according to the available measurements, lengthening of the double bonds in 1,3-butadiene as compared to ethylene "lies within the limits of experimental error, and, therefore, it is impossible to base on them any substantial conclusions as to the structure of conjugated systems."

C≡C bonds in diacetylene (HC≡C−C≡CH 1.19±0.03 A [12]), dimethyldiacetylene ($H_3CC{\equiv}C-C{\equiv}CCH_3$ 1.20±±0.02 A [12]), diphenyldiacetylene ($H_5C_6-C{\equiv}C-C{\equiv}C-C_6H_5$ 1.18 A [11]), and other acetylenes indicate, rather, the shortening of these bonds as compared to the length of the C≡C bond in acetylene (1.205±0.008 A), but in any case, they do not indicate lengthening of these bonds. The x-ray data available at the present time on the lengths of multiple bonds in π-conjugated systems also indicate no lengthening of these bonds. Thus, in one of the monograph collections on x-ray analysis of organic compounds, it is stated that the length of the C≡C bond in tolane is 1.19 A, and in stilbene the length of the C≡C bond is 1.33 A, that is, "not lengthened, which is in complete agreement with the situation found in other conjugated systems" [13].

As we have shown in previous work [14-16], at the present time opinions as to the changes in lengths of characteristic bonds can be formed with greater accuracy from their vibrational frequencies than from measurements of their lengths. In fact, an increase in the interatomic distance of a characteristic bond correlates strictly with the decrease in the vibrational frequency and the decrease in bond energy, while an increase in vibrational frequency and bond energy correlate with a decrease in bond length. At the present-day level of measuring techniques, the measurement of the vibrational frequency of bonds in molecules is carried out with enormously greater accuracy and ease than the measurement of the other two parameters mentioned above. This is especially important for C=C and C≡C bonds, since in these bonds (especially in the latter) the carbon atoms are already very close together, and their further approach is hindered by forces of repulsion which increase strongly at short distances. As a result, the curves of the vibrational frequencies of C=C and C≡C bonds rise sharply with an increase in interatomic distance; i.e., the significant increase in the vibrational frequencies of these bonds (especially the C≡C bond), which is readily established experimentally, corresponds to a quite insignificant reduction in interatomic distance, the direct measurement of which at the present-day level of technique of the appropriate measurements becomes lost in the limits of experimental error.

The presence in 1,3-butadiene and diacetylene of two multiple bonds leads to a splitting of their vibrational frequencies into two frequencies (mechanical effect of splitting of the frequency of coupled vibrations), one of which (the symmetric vibration) appears in Raman spectra and the other of which (the antisymmetric vibration) appears in infrared spectra. Let us turn first to data from Raman spectroscopy.

In conformity with the above, data from the Raman spectrum of 1,3-butadiene indicate a shortening of the C=C interatomic distance in comparison with ethylene: the characteristic frequency of the symmetric vibration of the C=C bonds in 1,3-butadiene (1638 cm^{-1})* is substantially higher than the vibrational frequency of the C=C bond in ethylene (1621 cm^{-1})**; this increase lies outside the limits of experimental error.

1,3-Butadiene can be considered as a mono-substituted ethylene. Among the possible substituents, there are those (the chlorine atom, etc.) which decrease the vibrational frequency of the double bond in ethylene, simultaneously increasing the interatomic distance; others (the methyl group, ethyl group, etc.) increase the vibrational frequency of the double bond in ethylene, simultaneously shortening the interatomic distance. From the frequency of the symmetric vibration of the double bond, 1,3-butadiene belongs to the second group of mono-substituted ethylenes:

	rA (C=C)	$\Delta\nu\ cm^{-1}$ (C=C) [17]
Ethylene	1.353 [9]	1621,
Vinylchloride.	1.380 [18]	1601,
Methylethylene. . . .	–	1648,
Ethylethylene.	–	1639,
1,3-Butadiene.	1.350 [8]	1638.

To still a greater degree than in 1,3-butadiene, this same thing appears in diacetylene. Along with a sharp decrease in the length of the single C−C bond (1.36±0.03 A) [12], the interatomic distance of the C≡C

*The Raman spectrum of 1,3-butadiene, which exists predominately in the trans-form, was taken in solution in cyclohexane with a domestic ISP-51 spectrograph with a standard camera using the excited line from a mercury lamp at 4358 A; $\Delta\gamma$ (cm^{-1}): 515 (4), 891 (1), 905 (1), 1014 (1), 1201 (4), 1309 (2), 1431 (4), 1638 (10), 3003 (6), 3087 (1).

**Liquid ethylene.

bond is also certainly shortened, as indicated by the very significant increase in the frequency of the symmetric vibration of these bonds as compared to the frequency of C≡C in acetylene (by 218 cm^{-1}).

If diacetylene is considered as a substituted acetylene, without any doubt it does not belong to that group of these compounds in which the substituent decreases the vibrational frequency and increases the interatomic distance of the C≡C bond (chlorine in chloroacetylene), but, on the contrary, it belongs to that group in which the substituent increases the vibrational frequency and shortens the interatomic distance, the effect being greater than that caused by the methyl group in methylacetylene:

	rA (C≡C)	$\Delta\nu\,cm^{-1}$ (C≡C) [17]
Acetylene	1.205 [10]	1965,
Chloroacetylene	1.210 [18]	— ,
Methylacetylene	1.200 [19]	2125,
Diacetylene	1.190 [12]	2183.

Thus, in the π-conjugated systems under consideration, in the symmetrical vibrational states of the multiple bonds there is a shortening of the interatomic distances. Conjugation, in this case, leads to a contraction of the molecular skeleton owing to the decrease in the lengths of both the single and the multiple bonds.

The frequency of the nonsymmetric vibration of the C≡C bond in diacetylene, which appears in the infrared spectrum (2085 cm^{-1}) [17], also considerably exceeds the frequency of the C≡C vibration in acetylene; the frequency of the nonsymmetric vibration of the C=C bonds in 1,3-butadiene is somewhat lower (1603 cm^{-1} [20]) than in ethylene. The average of the multiple-bond frequencies for the two vibrational states (symmetric and antisymmetric — 2134 cm^{-1}) indicates that in diacetylene the averaged, with respect to vibrational state, multiple bond* is shortened in comparison with the C≡C bond in acetylene; in 1,3-butadiene (1620 cm^{-1}), the averaged multiple bond is on a par with ethylene, and, in no case, is it lengthened in comparison with the double bond in ethylene.

We may point out that, together with A.D. Matveeva, we have investigated the Raman spectrum of hexachlorobutadiene, and in this spectrum there appear both symmetric (1611 cm^{-1}) and antisymmetric (1566 cm^{-1}) vibrations for the multiple bonds. The averaged frequency of these vibrations (1589 cm^{-1}) substantially exceeds the frequency of the vibration of the double bond in tetrachloroethylene (1571 cm^{-1}); i.e., in this compound the averaged length of the multiple bond is shorter than the ethylenic bond in tetrachloroethylene.

In previous work [14-16], we showed that an accurate optical experiment decisively refutes the hypothetical mesomeric-resonance theory with respect to certain mutual effects of the atoms in molecules, hyperconjugation of the first and second orders (σ,π - and σ,σ-conjugation), nor are the electronic shifts proposed by this theory in any way real. As seen from the material presented above, an accurate optical experiment also refutes the hypothetical mesomeric-resonance theory of conjugation (the mesomeric effect or effect of static conjugation, π,π-conjugation), showing that the electronic shifts proposed by this theory, which lead to mesomeric equalization of the bond lengths (including a lengthening of the multiple bonds) and, in addition, to an equalization of the electron densities of the bonds, are not real.**

*These averaged bond lengths are measured in x-ray and other investigations.

**In this theory, equalization of the electron density along the bonds is explained by geometrical considerations and certain mathematical operations, and, as emphasized by the authors themselves, this explanation is rough, qualitative, and very simplified, and, moreover, it is devoid of physical meaning [21]. More precisely, the theory maintains that in a conjugated system of π-bonds, the dumbbell ("figure-eight" type) of "p-orbital of the central C_2 atom overlaps to an equal degree the p-orbitals of each of the neighboring atoms" [22], which is also presumed to lead to equalization of the electron density along the bonds (for an illustration of the overlapping of p-orbitals, see [22]). The very history of the emergence, without basis, of these "dumbbells" ("figure-eights") in the presently considered theory indicates the incompetence of the concepts of this nature of the Copenhagen school of quantum mechanics in theoretical chemistry. As is well known, the "figure-eight" appeared as a graphical representation of the results of simplified evaluations of only the second of three terms in the expression for the probability of finding the single valence electron of hydrogen and hydrogen-like atoms in the p-state in the vicinity of the nucleus $_1P=\psi\bar{\psi}dV=\Phi_m\bar{\Phi}_m\cdot[\vartheta_{ml}]^2\cdot[R_{nl}]^2$); this term characterizes the indicated probability in

(Footnote continued on next page)

3. Contraction of molecules with conjugated bonds occurs owing to interaction of pairs of π-electrons (through interaction of their electromagnetic and other fields) localized in the 1,2-, 3,4- and other bonds. Two facts indicate the presence of this interaction and its distribution along the entire system of conjugated bonds: 1) a shift in the ultraviolet absorption bands toward longer wavelengths with an increase in the units in the polymethylene chain, the large number of interacting π-electrons involved in the transition from ethylene to a polymethylene chain (ethylene – 193, 1,3-butadiene – 217, hexatriene – 258, and octatriene – 286 mμ [25]) having an effect on this shift; 2) the lack of free rotation around the C–C single bond. One of the clearest proofs of the fact that contraction of a conjugated molecular system occurs through the direct interaction of pairs of π-electrons localized in 1,2-, 3,4-, etc. bonds is the structure of diacetylene. The contraction in diacetylene of the C–C distance to the interatomic distance in C=C double bonds (1.36 A [12]) is not accompanied by the appearance of a vibrational frequency in the region characteristic for it, since possession of another pair of electrons at the 2,3-atoms is required for the appearance of this frequency (i.e., an additional force interaction). This requirement is not met, since the two pairs of π-electrons are localized in the 1,2- and 3,4-bonds, thereby providing for the full-valued acetylenic character of these bonds and making them even shorter and stronger, as we have seen. Acting as though "from without," the interacting pairs of π-electrons localized in the 1,2- and 3,4-bonds draw together the atoms in the C–C bond to a distance of 1.36 A (instead of 1.55 A) without converting this bond to a multiple bond (double); the force constants of the central C–C single bond in diacetylene (as in dimethyldiacetylene), calculated taking into account its vibrational frequency, are significantly (more than 20%) lower than for ethane [26]. A similar picture holds for 1,3-butadiene and other conjugated systems.

4. Understanding of the dual reactivity of 1,3-butadiene must come from an understanding of its real structure as characterized above and from the dynamic concepts relative to the nature of the molecule, as developed in the theory of chemical structure by A.M. Butlerov and also by V.V. Markovnikov and M.A. Il'inskii.*

The most electronized regions in 1,3-butadiene [14-16] are the regions of the double bonds, and the most electronized locales in these regions are the 1- and 4-carbon atoms, which are in methylene, not methyne, groups, as indicated by the high vibrational frequencies of the methylene groups, particularly in their antisymmetric vibrational state.**

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terms of only one polar coordinate – the angle ϑ (the "latitude"). Specific characteristics of this case are spherical symmetry of the field, one valence electron, and the absence of the action of an external field. But, at the beginning of the 1930's, in the theory under consideration, the "figure-eight" was transferred arbitrarily [23] to the p electrons of the carbon atom and, moreover, to carbon atoms in molecules with π-bonds; i.e., the "figure-eight" was extended to the case in which all of the most important conditions for its occurrence (spherical symmetry, etc.) are completely absent. The question became merely how to dispose this "figure-eight" in the coordinate system to obtain the desired calculated results – minimum energy of the system. It developed that for this purpose, the axes of the "figure-eights" had to be parallel to each other, perpendicular to the line of the bond between carbon atoms; in π-conjugated systems, the p-orbital of the central atom must equally overlap with the p-orbitals of the neighboring atoms [22]; all of this mathematically guarantees the maximum value of the exchange integral (overlap integral) and, thereby, a minimum value of the energy of the system [24]. Such an arbitrary transfer of a simplified, single-coordinate, mathematical scheme of the electron density of hydrogen and hydrogen-like atoms with their spherically symmetrical fields to complicated molecular systems with the further arbitrary mathematical assumptions for the purpose of obtaining a calculated minimum energy for the system in no way reflects physical reality, nor does it rest on any physical experiment, and it is disproved by the other experimental, physical data cited above.

*With this "dynamic point of view of the nature of a chemical compound" [27, 28] (cf. [15, 16]), A.M. Butlerov discovered the phenomenon of tautomerism, and he explained by it the dual reactivity of various compounds [28]. With particular vigor, M.A. Il'inskii developed dynamic concepts regarding molecules (for details, see [29]), and first predicted, on the basis of the theory of chemical structure after its appearance, the existence of free radicals, particularly methyl free radicals. A radical is an independent, internally self-equilibrating, dynamic particle if the radical, as M.A. Il'inskii wrote, "can exist in the free form even though only over the course of an infinitely small time" [30]. These dynamic concepts, which are justified by the entire development of organic chemistry, can clarify for us, in connection with the material presented above, the essence of the mechanism of the reaction occurring during addition to 1,3-butadiene in the 1,2- and 3,4-positions.

**Concerning this, see [14-16, 31].

The frequencies of the methyne and methylene groups are (in cm^{-1}):

	Paraffins*	1,3-Butadiene
CH	2870	3003
CH_2	2853, 2908	3003, 3087

It is natural that the positive end, X, of a molecule of reagent (X is H^+, Cl^+, Br^+, etc.) is directed toward these regions of the molecule; on completion of polarization in the reagent molecules, the positive end adds to one of the terminal atoms of the system with the formation of the ion $XH_2C-\overset{+}{C}H-C=CH_2$. This is the first stage, with respect to time, in the addition reaction. Ionization of the 1,3-butadiene molecule with the formation of a positively charged carbon atom in the 2-position imparts a corresponding impulse to the remaining pair of π-electrons, thereby bringing about the transition of (VIII) to (IX). But the presence in (IX) of a C^+ atom at the end of the chain in turn imparts an impulse to the transition of (IX) to (VIII); i.e., the following tautomerism of the carbonium ions is established:

$$\underset{\text{(VIII)}}{XH_2C-\overset{+}{C}H-CH=CH_2} \rightleftarrows \underset{\text{(IX)}}{XH_2C-CH=CH-\overset{+}{C}H_2}.$$

This definitely involves two tautomeric, separately existing ions which differ in their chemical structure (in the order of the bonds), and not a single mesomeric or hybrid ion [(VIII) $\longleftrightarrow$ (IX) or $XH_2C-CH-CH=CH_2$]. Depending on the reaction conditions, the addition of the negative ion (Cl^-, Br^-) can be to particle (VIII) in the 2-position or to particle (IX) in the 4-position. In order for these reactions to take place, the ions (VIII) and (IX) must be – must exist as – separate particles, though their lifetime be infinitely small. The presence of products of addition at the 1,2- and 1,4-positions is, in turn, proof of the existence of the indicated tautomeric ions as individual particles.

SUMMARY

1. The explanation of the dual reactivity of π-conjugated systems by hypotheses based on the mesomeric effect (static conjugation) in the unreacting molecule and on first order hyperconjugation in the intermediate carbonium ion are not authentic. Such systems (1,3-butadiene, diacetylene, hexachlorobutadiene) do not have mesomeric structures with equalized bonds as proposed by the indicated theory; in particular, their multiple bonds are not lengthened.

2. The first stage of the reaction – polarization of the reagent and the addition of its cation to the end of the molecule – promotes increased electronization of the methylene groups in 1,3-butadiene. The dual reactivity of 1,3-butadiene is brought about by this first stage of the reaction, and is due entirely to the separate existence in space of the ions (VIII) and (IX), which differ in their chemical structures, during the tautomeric transformation of one to the other.

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SIGNIFICANCE OF ABBREVIATIONS MOST FREQUENTLY ENCOUNTERED IN SOVIET PERIODICALS

FIAN	Phys. Inst. Acad. Sci. USSR.
GDI	Water Power Inst.
GITI	State Sci.-Tech. Press
GITTL	State Tech. and Theor. Lit. Press
GONTI	State United Sci.-Tech. Press
Gosenergoizdat	State Power Press
Goskhimizdat	State Chem. Press
GOST	All-Union State Standard
GTTI	State Tech. and Theor. Lit. Press
IL	Foreign Lit. Press
ISN (Izd. Sov. Nauk)	Soviet Science Press
Izd. AN SSSR	Acad. Sci. USSR Press
Izd. MGU	Moscow State Univ. Press
LEIIZhT	Leningrad Power Inst. of Railroad Engineering
LET	Leningrad Elec. Engr. School
LETI	Leningrad Electrotechnical Inst.
LETIIZhT	Leningrad Electrical Engineering Research Inst. of Railroad Engr.
Mashgiz	State Sci.-Tech. Press for Machine Construction Lit.
MEP	Ministry of Electrical Industry
MES	Ministry of Electrical Power Plants
MESEP	Ministry of Electrical Power Plants and the Electrical Industry
MGU	Moscow State Univ.
MKhTI	Moscow Inst. Chem. Tech.
MOPI	Moscow Regional Pedagogical Inst.
MSP	Ministry of Industrial Construction
NII ZVUKSZAPIOI	Scientific Research Inst. of Sound Recording
NIKFI	Sci. Inst. of Modern Motion Picture Photography
ONTI	United Sci.-Tech. Press
OTI	Division of Technical Information
OTN	Div. Tech. Sci.
Stroiizdat	Construction Press
TOE	Association of Power Engineers
TsKTI	Central Research Inst. for Boilers and Turbines
TsNIEL	Central Scientific Research Elec. Engr. Lab.
TsNIEL-MES	Central Scientific Research Elec. Engr. Lab.–Ministry of Electric Power Plants
TsVTI	Central Office of Economic Information
UF	Ural Branch
VIESKh	All-Union Inst. of Rural Elec. Power Stations
VNIIM	All-Union Scientific Research Inst. of Meteorology
VNIIZhDT	All-Union Scientific Research Inst. of Railroad Engineering
VTI	All-Union Thermotech. Inst.
VZEI	All-Union Power Correspondence Inst.

Note: Abbreviations not on this list and not explained in the translation have been transliterated, no further information about their significance being available to us. – Publisher.